University of Zurich^UZH

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DARWIN

DARWIN - A NEXT-GENERATION OBSERVATORY FOR DARK MATTER AND NEUTRINO PHYSICS

LAURA BAUDIS
UNIVERSITÄT ZÜRICH

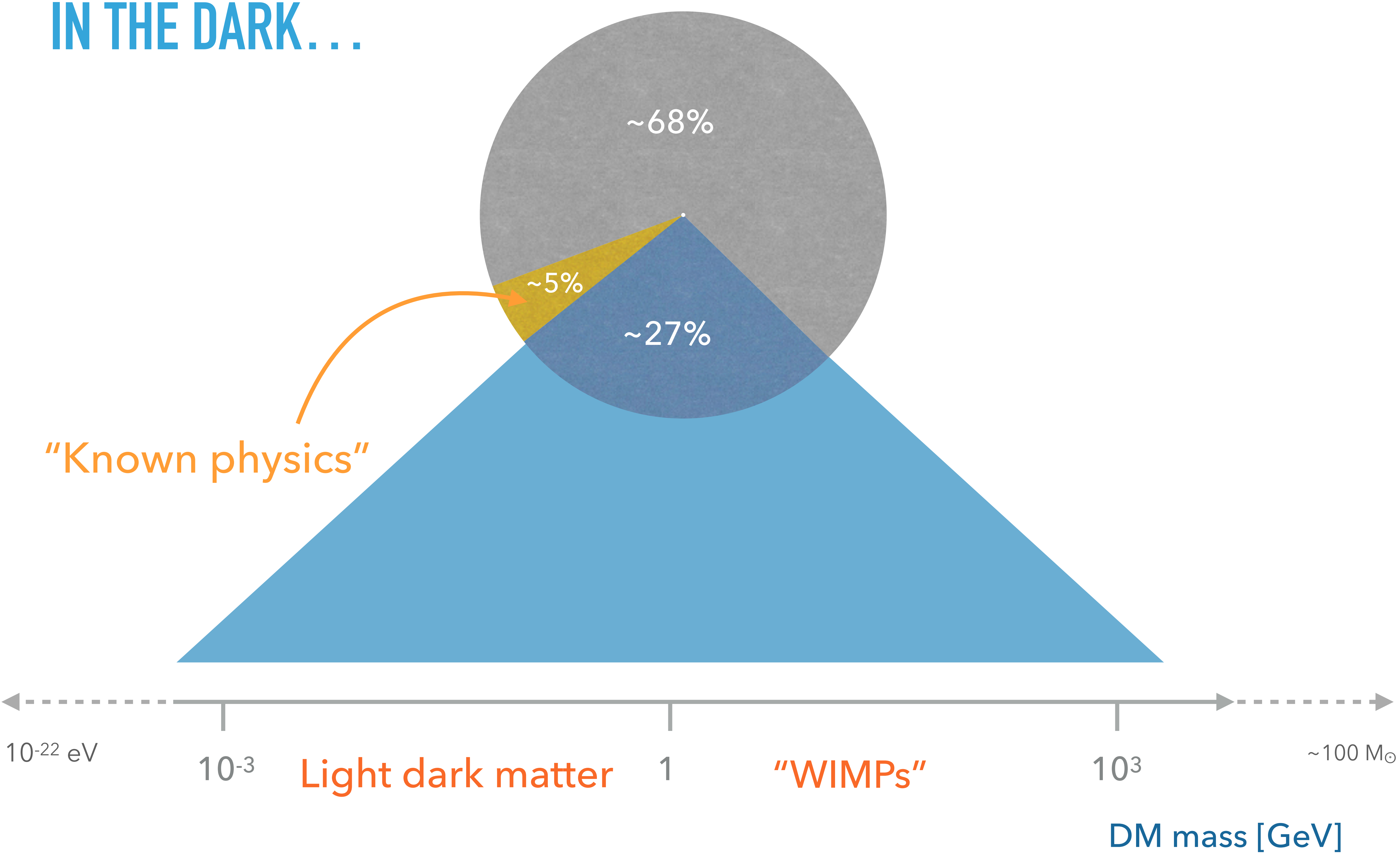
VIRTUAL SNOLAB SEMINAR
AUGUST 24, 2020

SNOLAB

SOME KEY OPEN QUESTIONS IN PARTICLE PHYSICS

- The nature of dark matter
- Baryogenesis
- The strong CP problem
- The fermion mass spectrum and mixing
- The cosmological constant
- …
    - Some of these can be addressed *with liquid xenon detectors operated deep underground*
    - Demonstrated excellent sensitivities and scalability to large target masses

IN THE DARK…



~68%

~5%

~27%

"Known physics"

10^{-22} eV

10^{-3}

Light dark matter

1

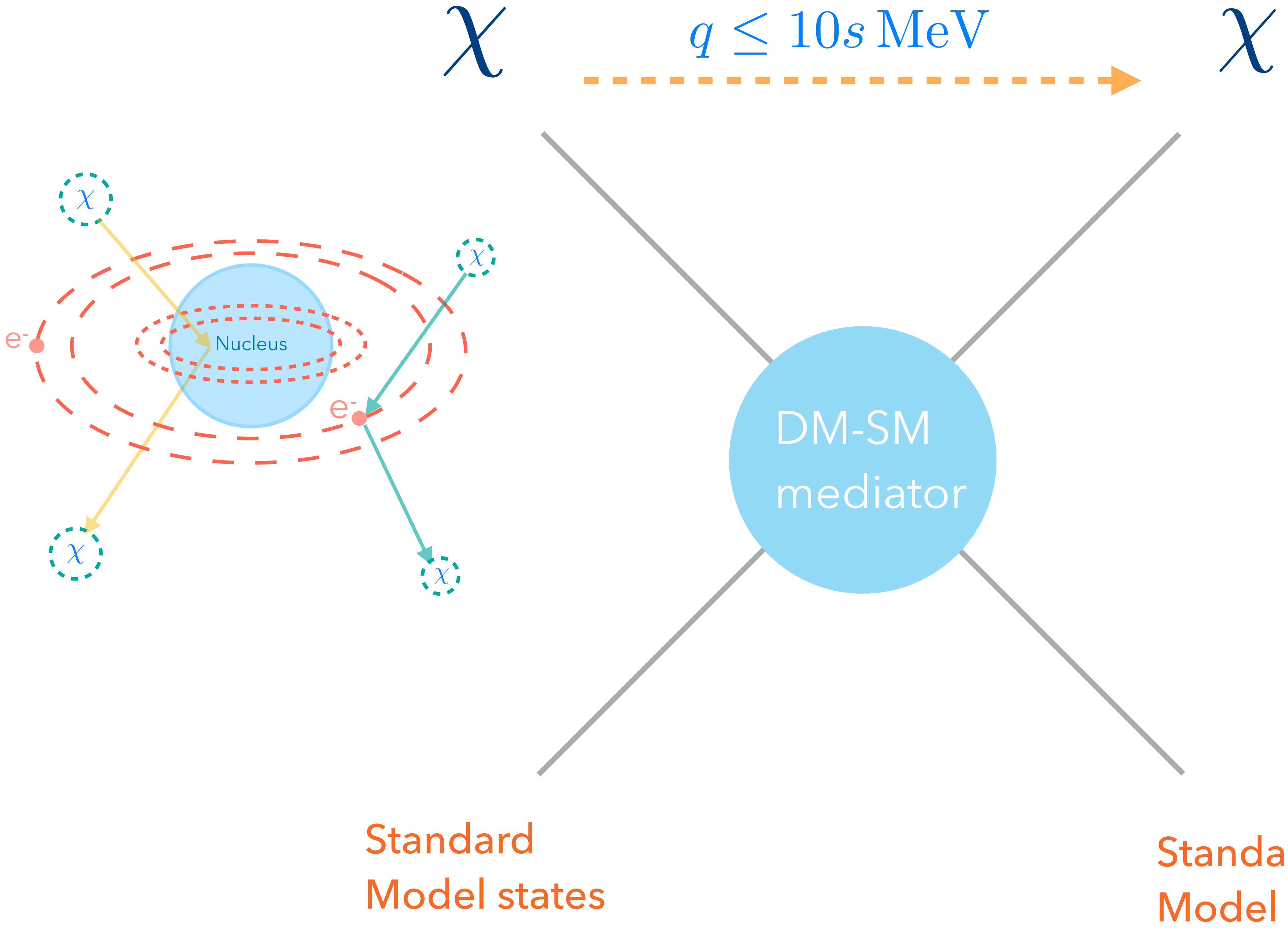
"WIMPs"

10^{3}

~100 $M_\odot$

DM mass [GeV]

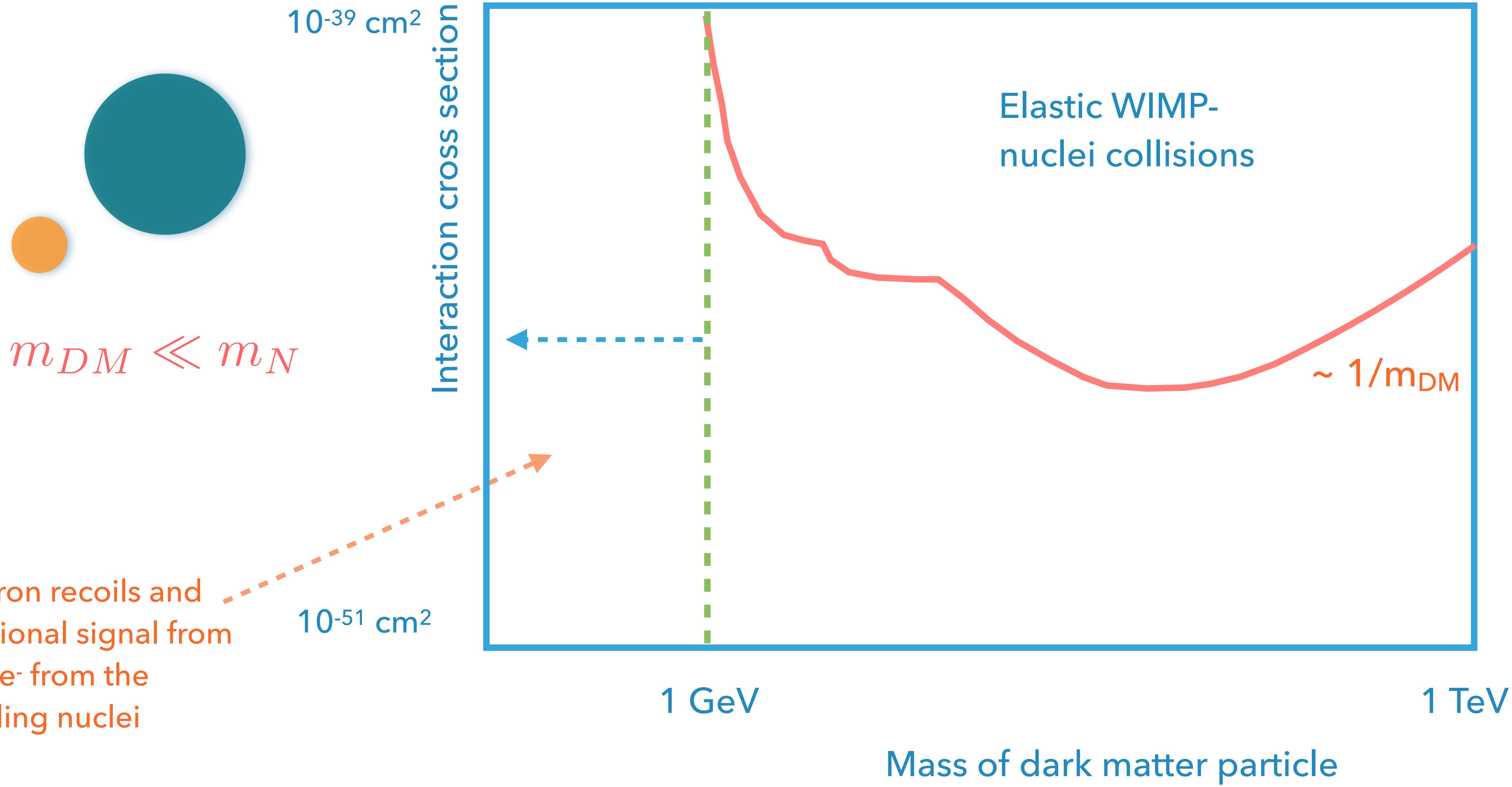
DIRECT DARK MATTER DETECTION



- collisions with electrons in the atomic shell, or absorption of light bosons via the axio-electric effect
- Bremsstrahlung from polarised atoms; e- emission due to so-called Migdal effect

see e.g., Kouvaris, Pradler, McCabe; M. Ibe et al.

DM INTERACTION CROSS SECTION VS MASS

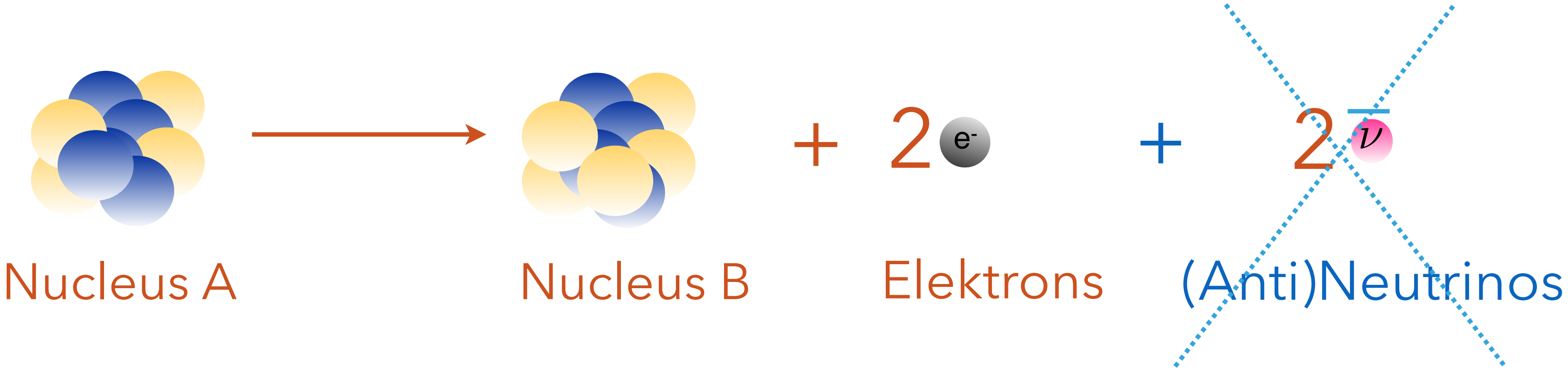


$m_{DM} \ll m_N$

Electron recoils and additional signal from shell e^- from the recoiling nuclei

NEUTRINOLESS DOUBLE BETA DECAY

- Some of the open questions in neutrino physics can be addressed with an extremely rare nuclear decay process: the neutrinoless double beta decay
    - What is the nature of neutrinos? Are they Dirac or Majorana particles?
    - What are the absolute values of neutrino masses, and the mass ordering?
    - What is the origin of small neutrino masses?



NEUTRINOLESS DOUBLE BETA DECAY

- Can only occur if neutrinos have mass and if they are their own antiparticles => ΔL = 2

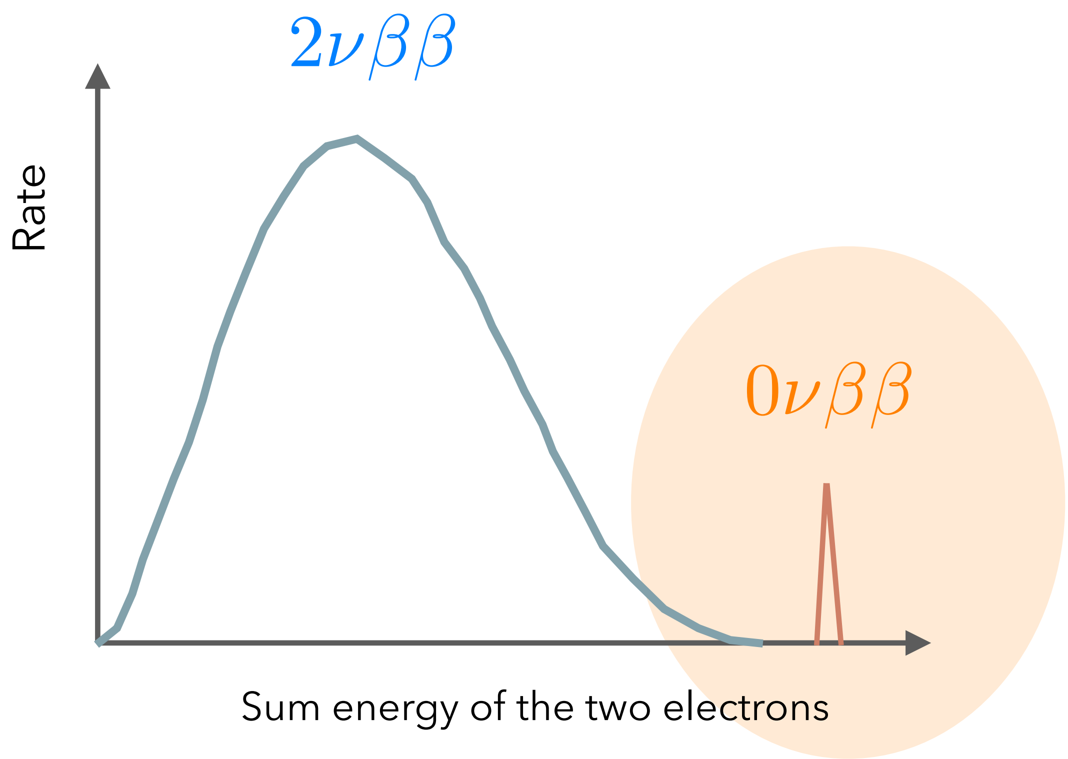
$$T_{1/2}^{0\nu\beta\beta} > 10^{24}\,\mathrm{y}$$

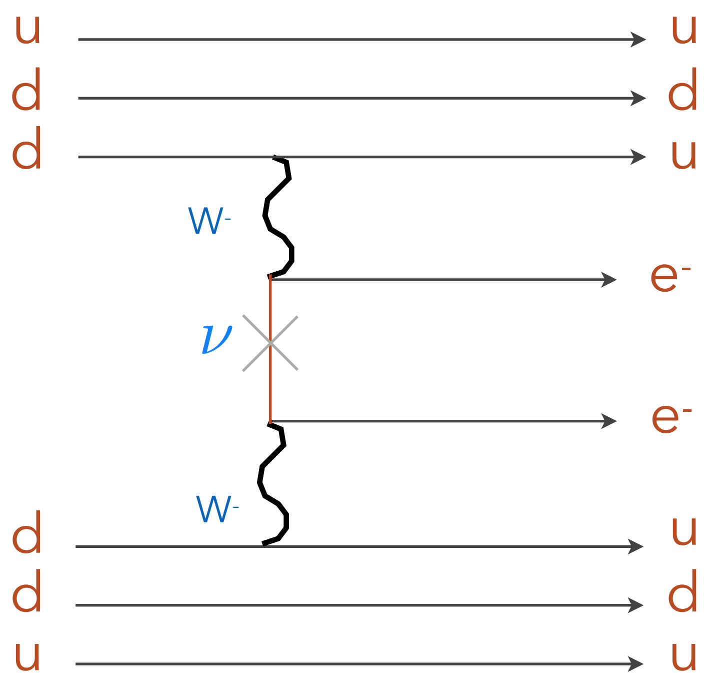
- Expected signature: *sharp peak at the Q-value of the decay*

$$Q = E_{e1} + E_{e2} - 2m_e$$

The double beta decay without neutrinos: first discussed by Wendell H. Fury in 1939

Ettore Majorana had proposed in 1937 that neutrinos could be their own antiparticles

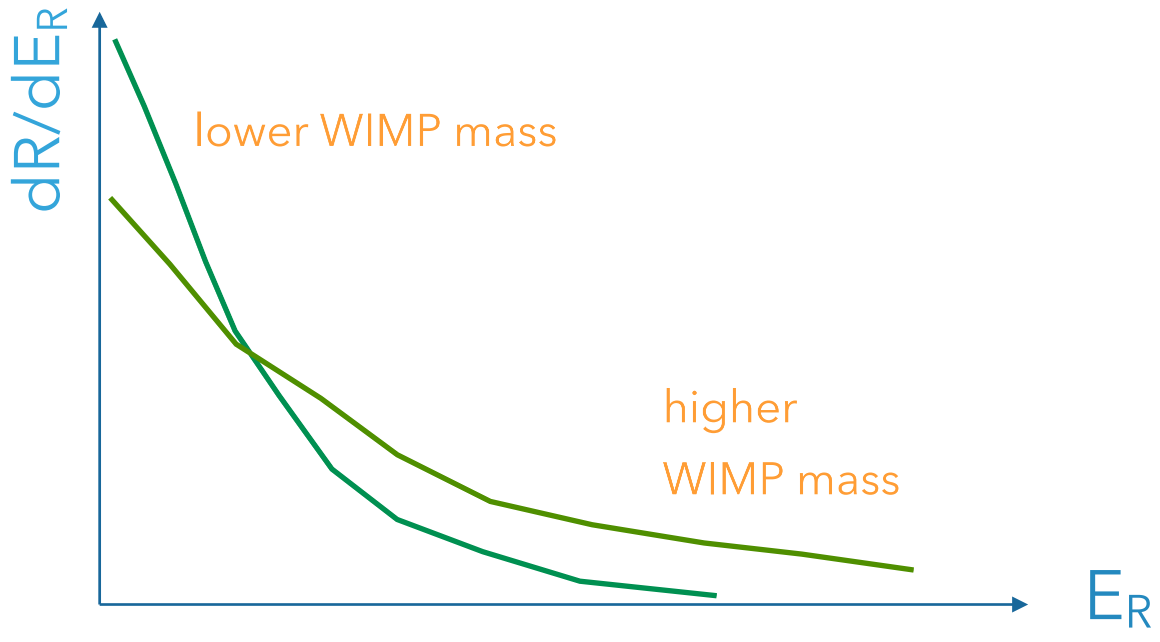


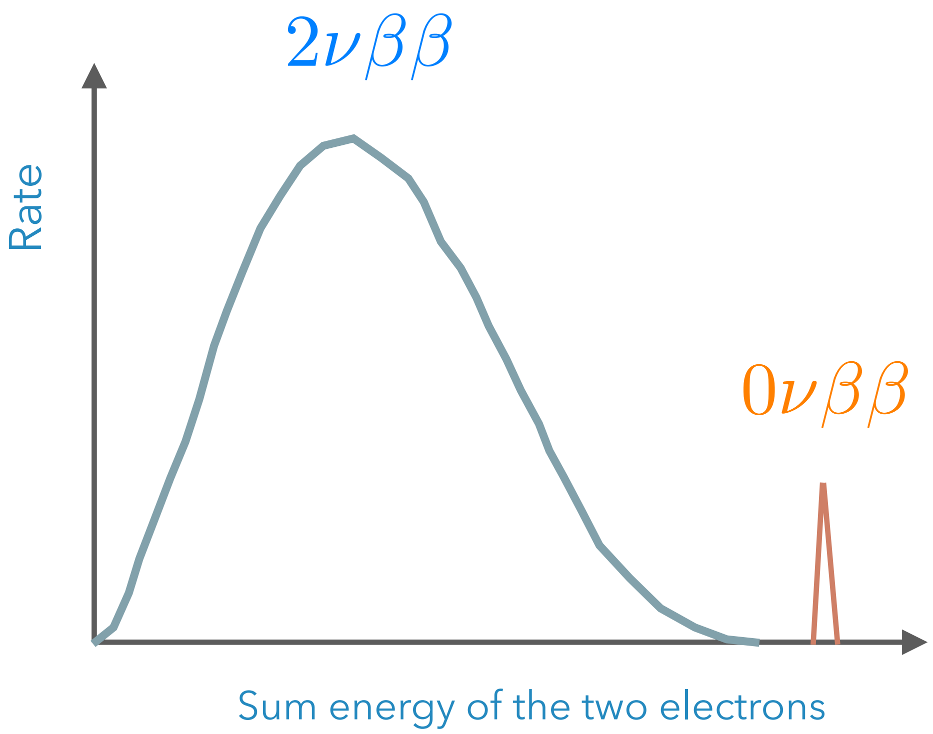


DARK MATTER & DOUBLE BETA DECAY EXPERIMENTS

- Nuclear recoils: ~keV-energies
- Featureless recoil spectrum
- Very low event rates: < 0.1/(kg x year)

- Q-values: MeV-scale
- Peak at the Q-value
- Very low event rates: <0.1/(kg x year)





MAIN EXPERIMENTAL REQUIREMENTS

- Low energy thresholds
- Large detector masses
- Ultra-low backgrounds
- Excellent signals versus background discrimination

$$R \propto N \frac{\rho}{m_\chi} \sigma \langle v \rangle$$

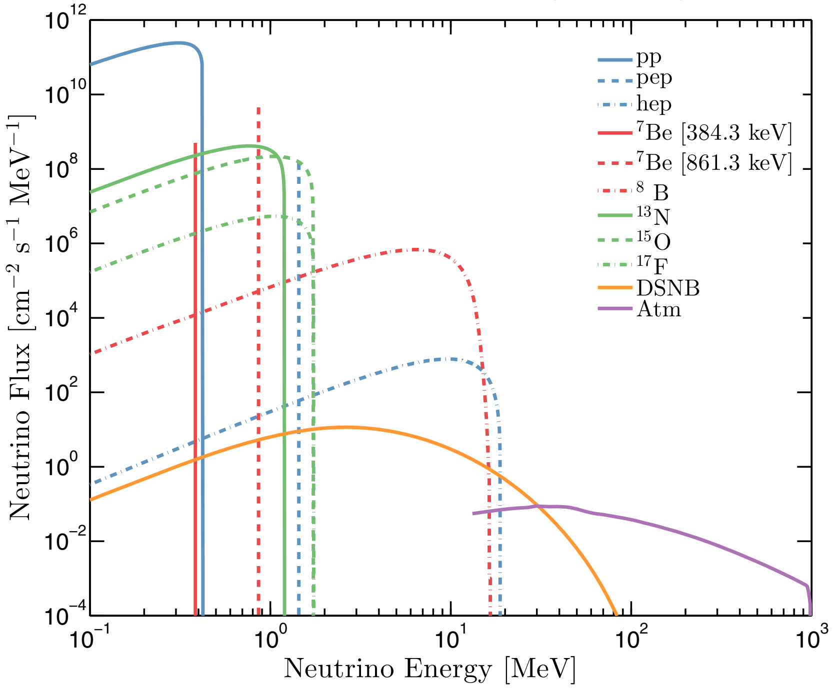
- Excellent energy resolution
- Large detector masses
- Ultra-low backgrounds
- Excellent signals versus background discrimination

$$N_{\beta\beta} \propto \lambda_{\beta\beta} N t$$

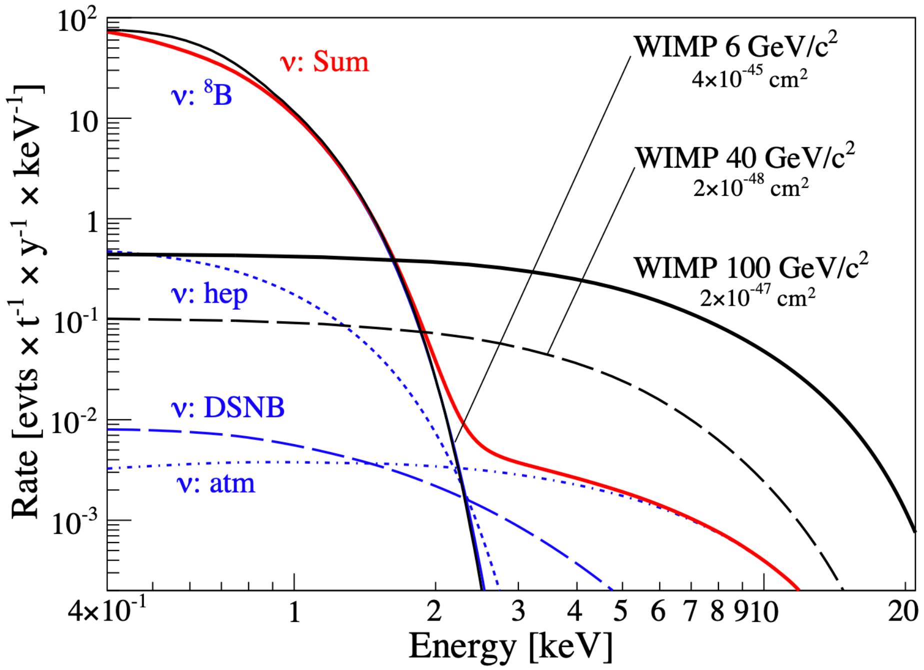
BACKGROUNDS

- In the ideal case: below the expected signal
  - Muons & associated showers; cosmogenic activation of detector materials
  - Natural (^{228}U, ^{232}Th, ^{40}K) and anthropogenic (^{85}Kr, ^{137}Cs) radioactivity: γ, e^-, α, n
  - Neutrinos: coherent elastic neutrino-nucleus scattering (DM) and elastic neutrino-electron scattering (DM and 0νββ-decay)

C.A.J. O'Hare , PRD94, 2016

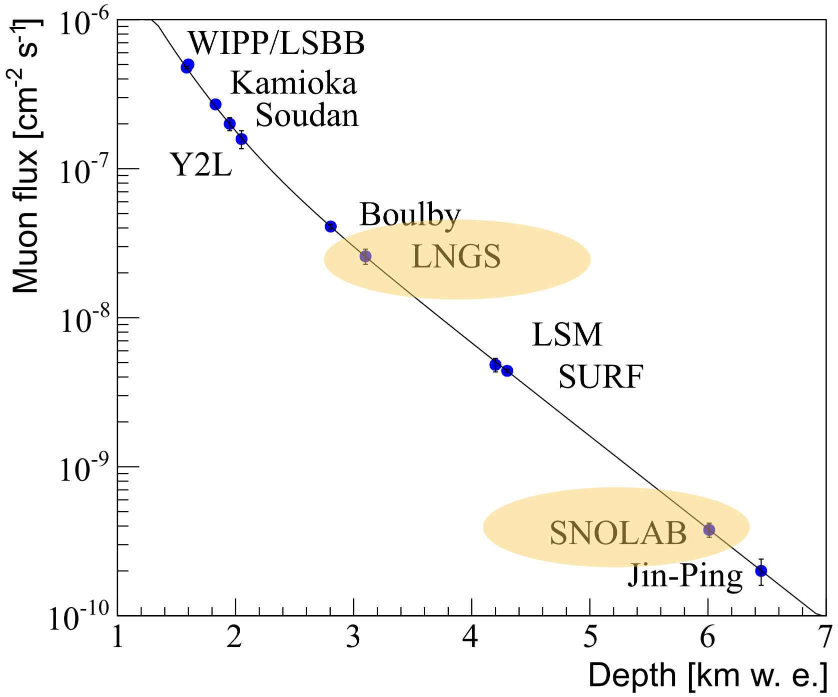


LB et al., JCAP01 (2014) 044



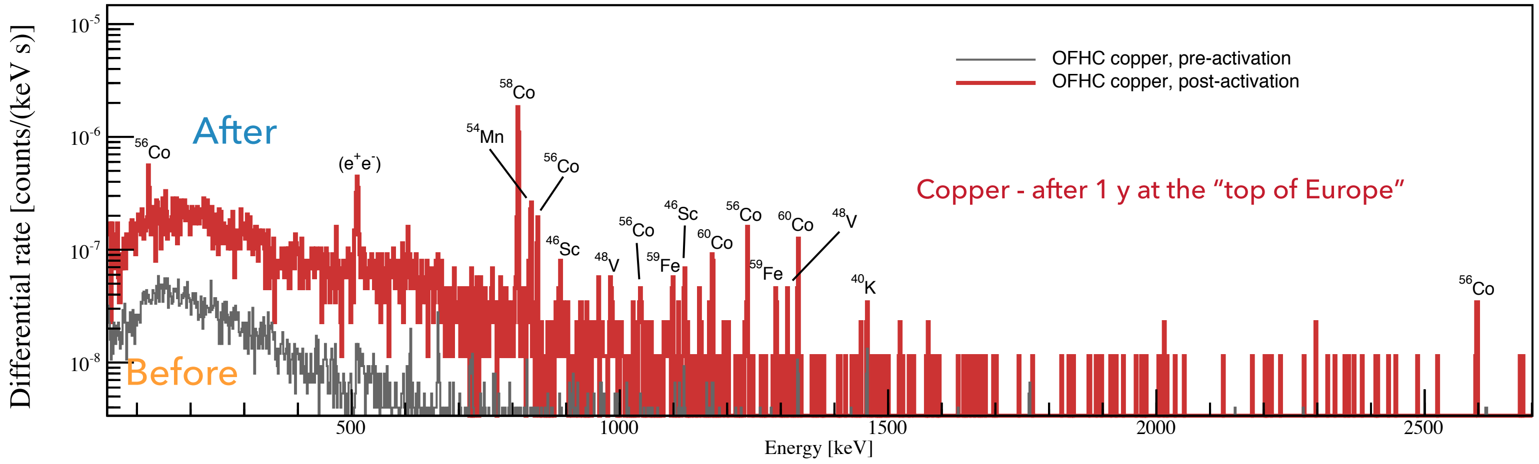
BACKGROUND REDUCTION

- Go deep underground



- Avoid cosmic activation

LB et al., Eur. Phys. J. C75 2015

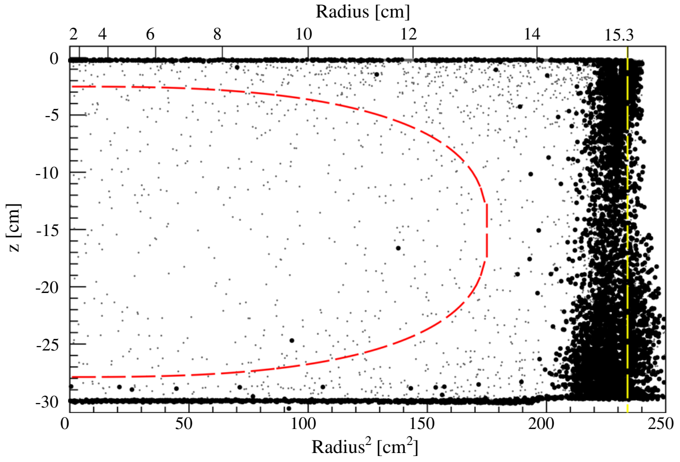


After

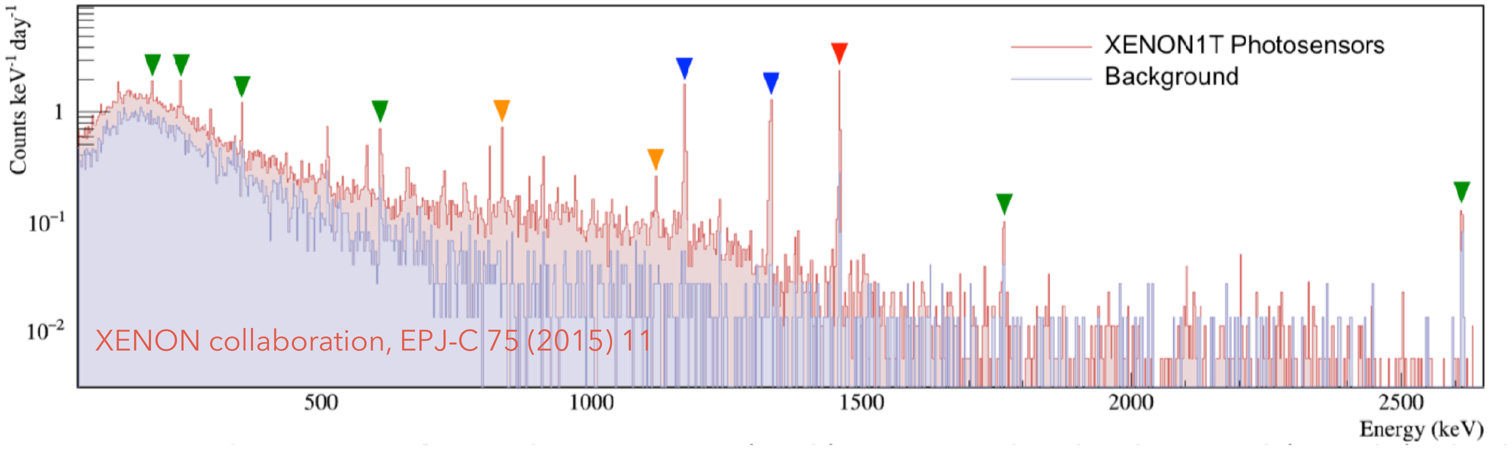
Before

Copper - after 1 y at the “top of Europe”

- Fiducialize

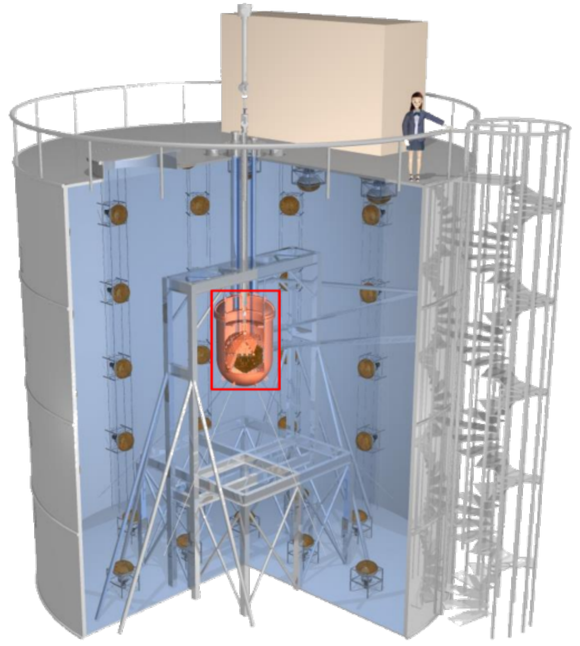


- Select low-radioactivity materials



XENON collaboration, EPJ-C 75 (2015) 11

- Use active shields



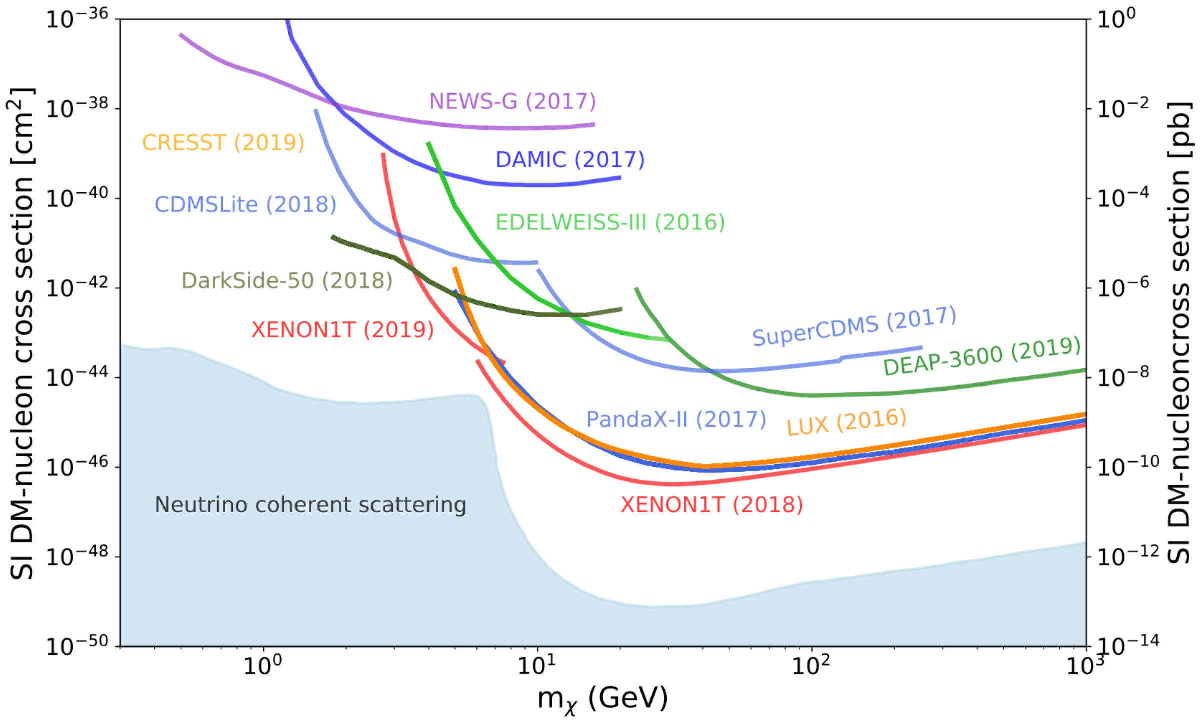
EXPERIMENTAL STATUS: OVERVIEW

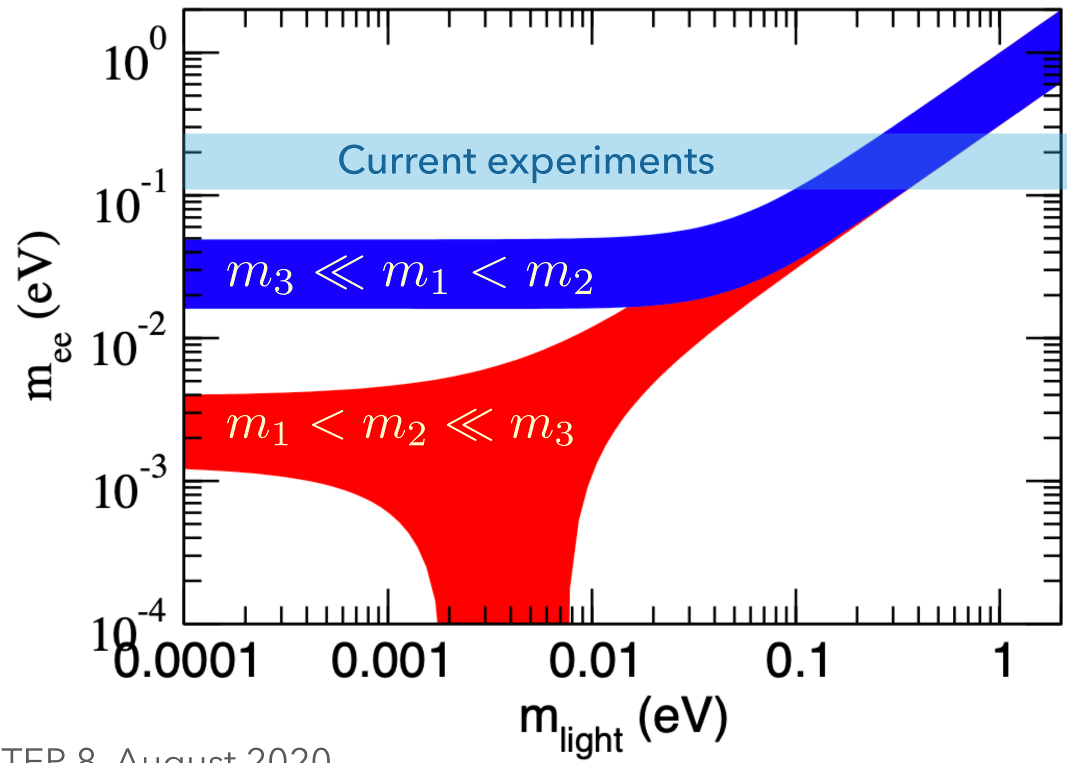
- No evidence for dark matter particles
- Probing scattering cross sections (on nucleons) of ~ a few x 10^{-47} cm^2

$$\sigma_{\rm SI} < 4.1 \times 10^{-47} {\rm cm}^2 \ {\rm at}\ 30\,{\rm GeV}/{\rm c}^2$$

- No evidence for the neutrinoless double beta decay
- Probing half-lives up to 1.8 x 10^{26} years

$$m_{\beta\beta} < (0.08 - 0.18)\,{\rm eV}\,(90\%\ {\rm C.L.})$$

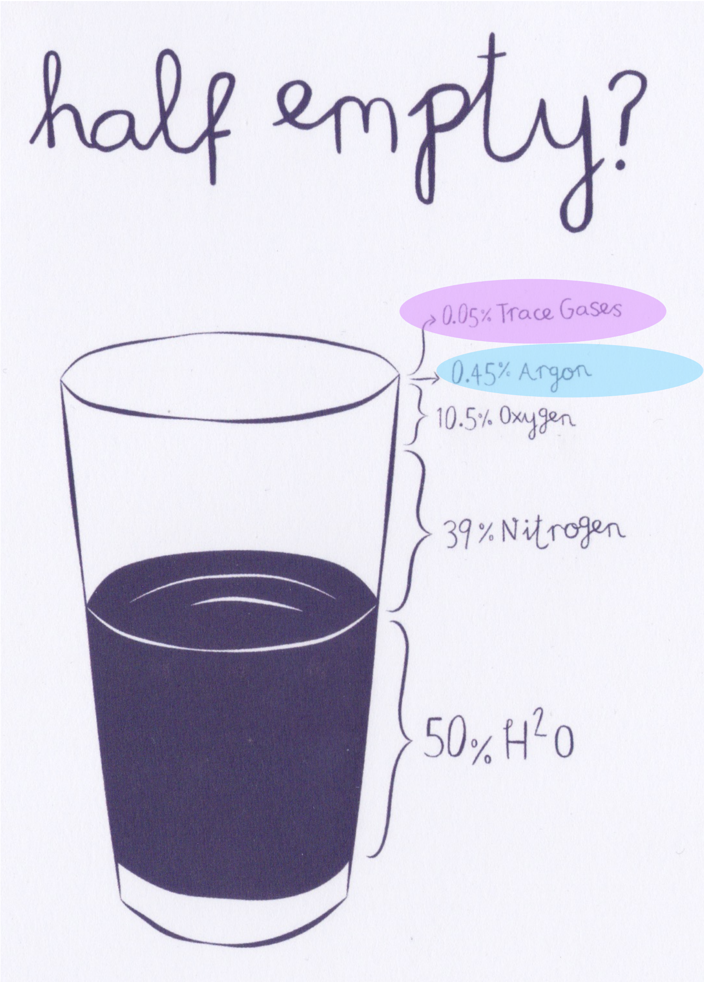


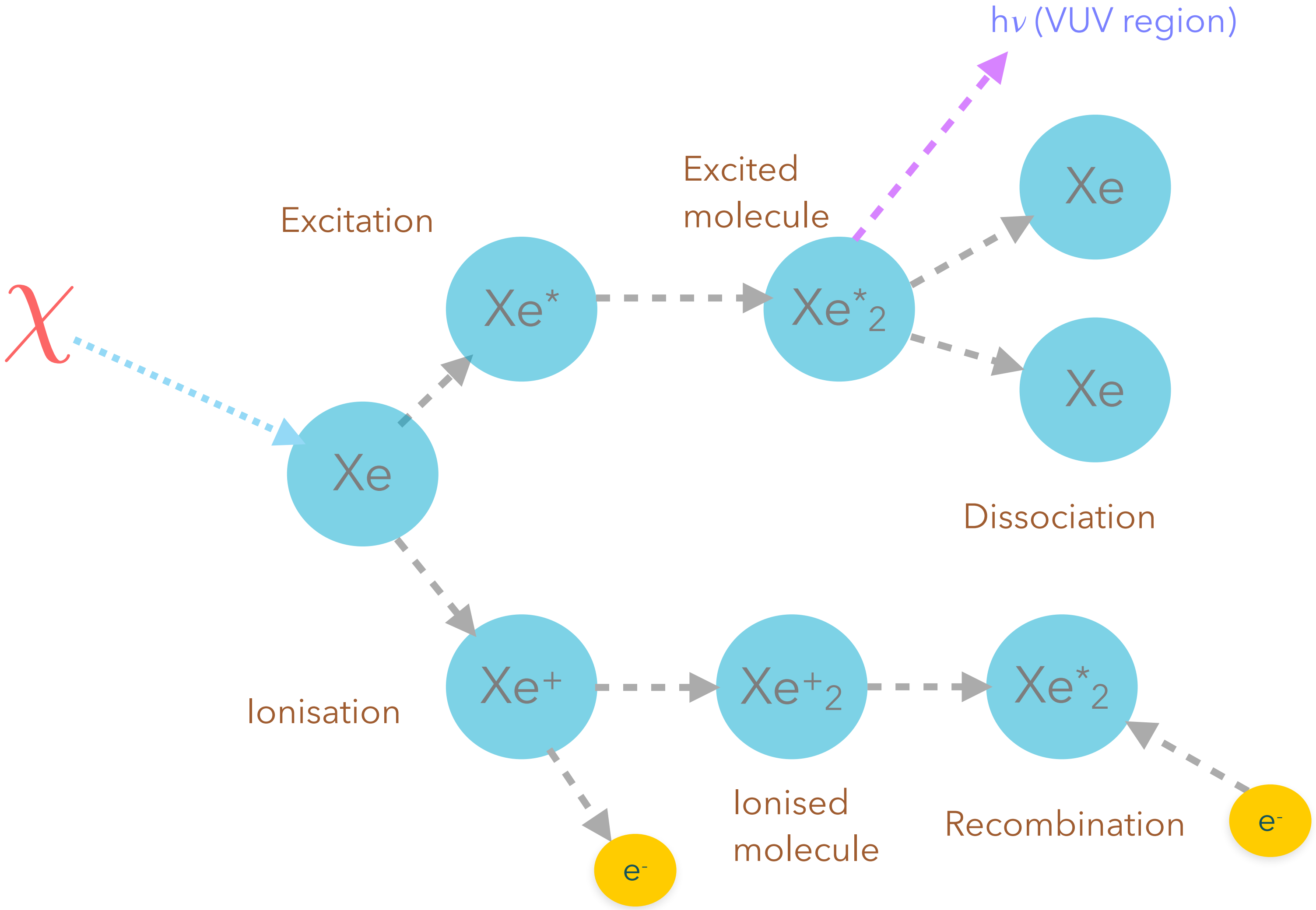


PDG Review: PTEP 8, August 2020

THE DARWIN EXPERIMENT

- Will use a large amount of clean liquid xenon target & detect ionisation and excitation from particle interactions
- Xenon: "the strange one", concentration in the atmosphere: 87 ppb* (by volume)





$h\nu$ (VUV region)

χ

Xe

Excitation

Xe^*

Excited molecule

Xe^*_2

Xe

Xe

Dissociation

Ionisation

Xe^+

e^-

Xe^+_2

Ionised molecule

Xe^*_2

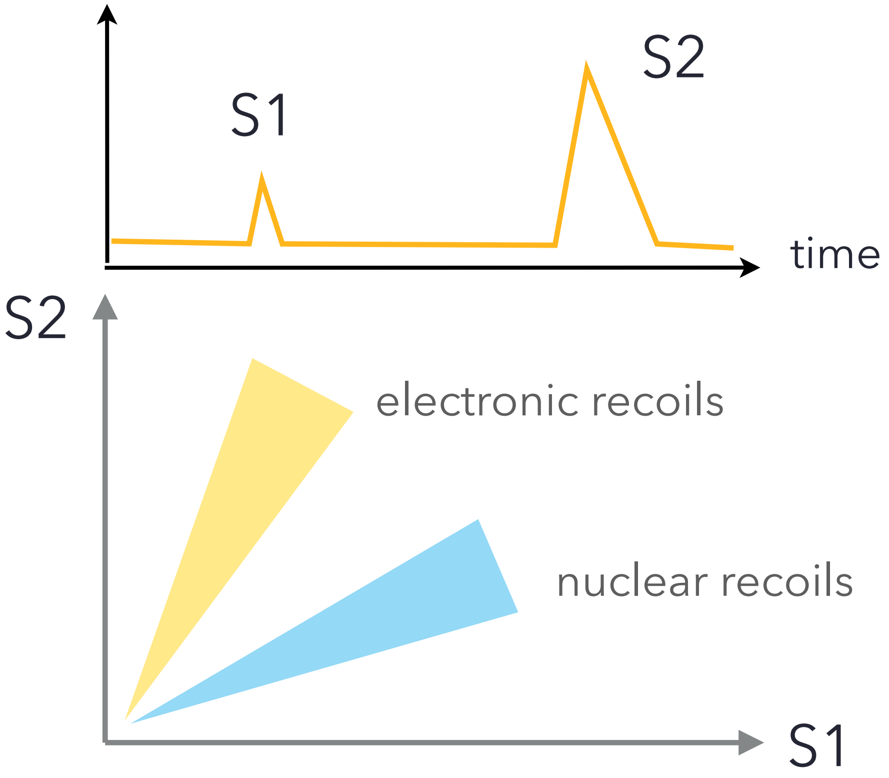
Recombination

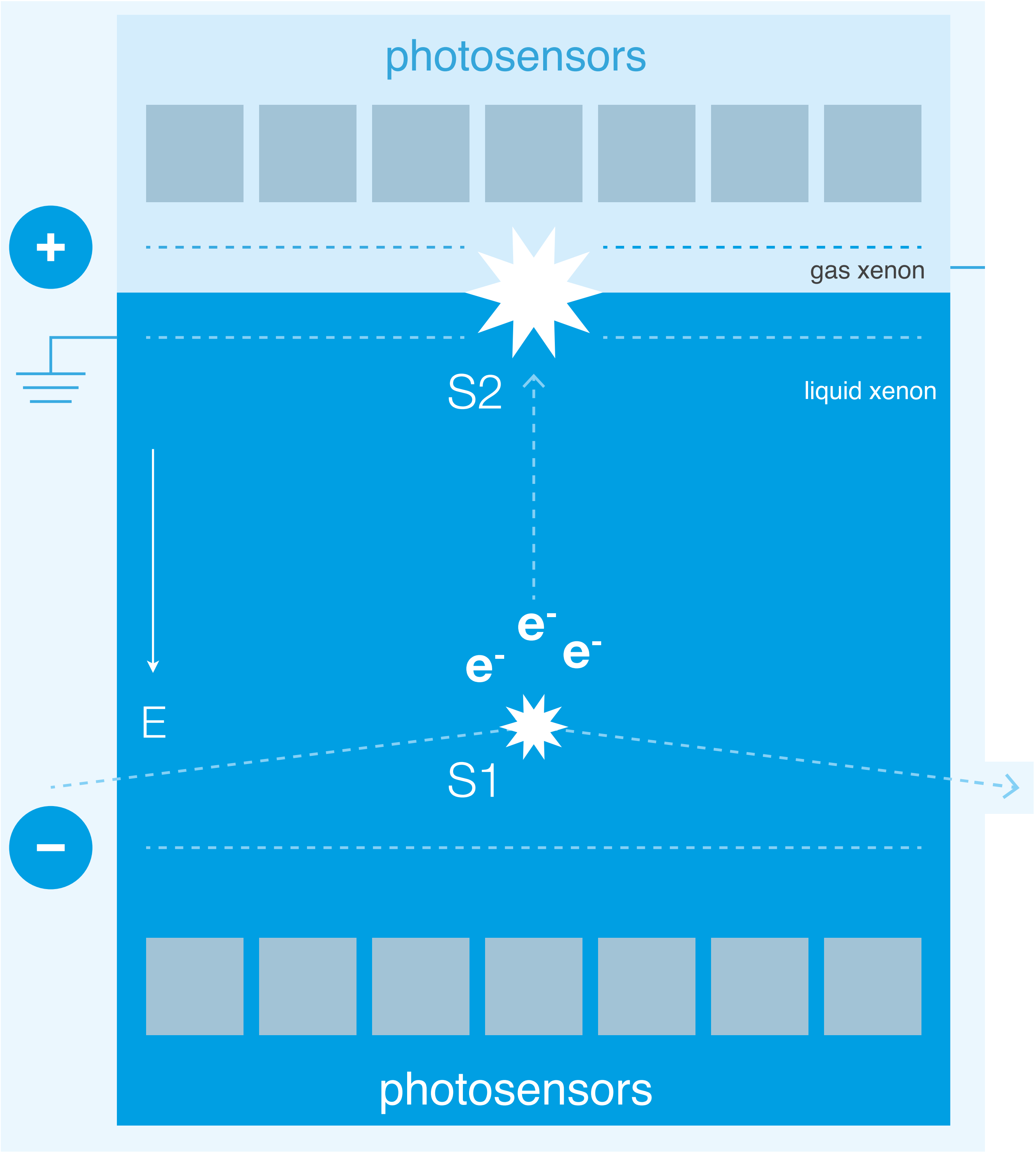
e^-

*https://doi.org/10.1007/978-3-319-39312-4_202

DETECTION PRINCIPLE: A TWO-PHASE TPC

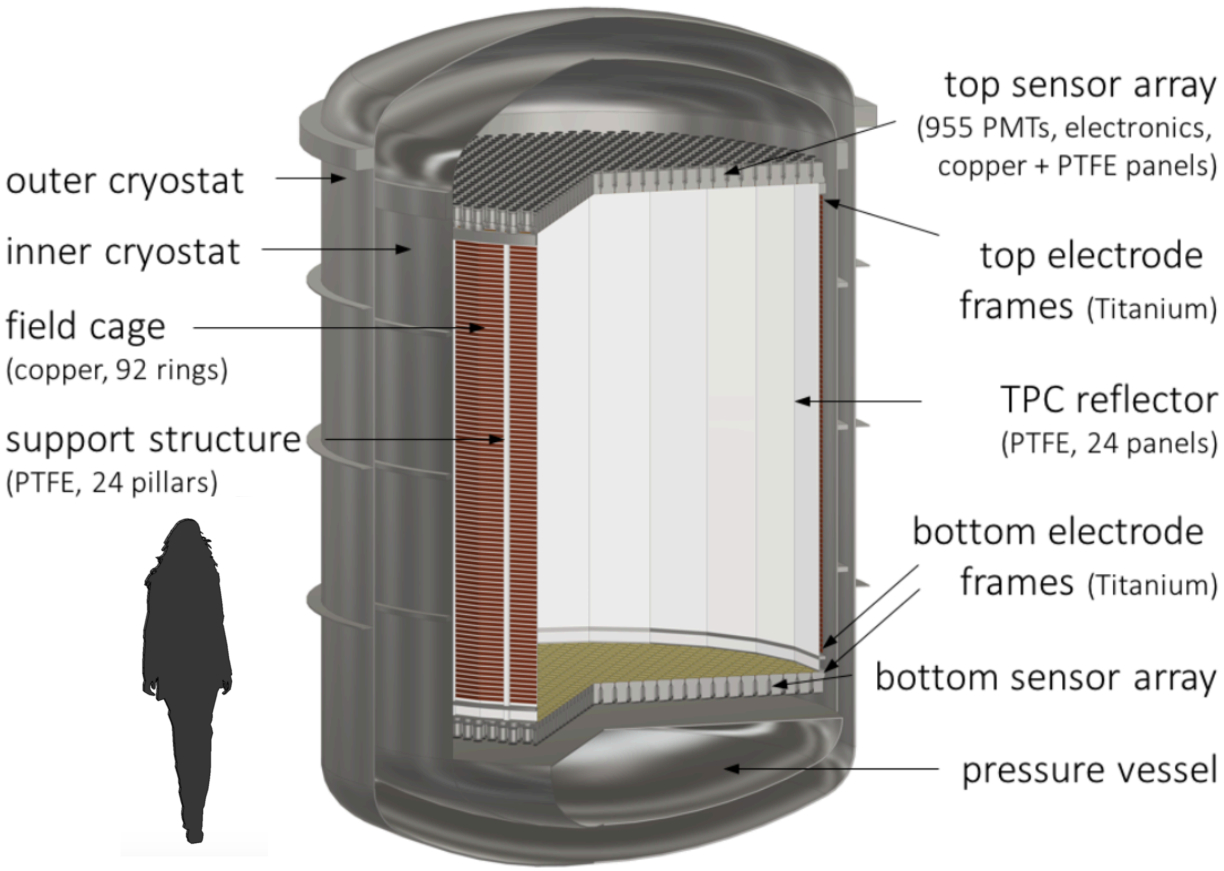
- 3D position resolution via light (S1) and charge (S2) signals
- S2/S1 depends on particle ID
- Fiducialisation
- Single versus multiple interactions





DARWIN DESIGN: BASELINE SCENARIO

- Two-phase TPC: 2.6 m ø, 2.6 m height
- 50 t (40 t) LXe in total (in the TPC)
- Two arrays of photosensors (e.g. 1800 3-inch PMTs)
- PTFE reflectors and copper field shaping rings
- Low-background, double-walled titanium cryostat
- Shield: Gd-doped water, for μ and n

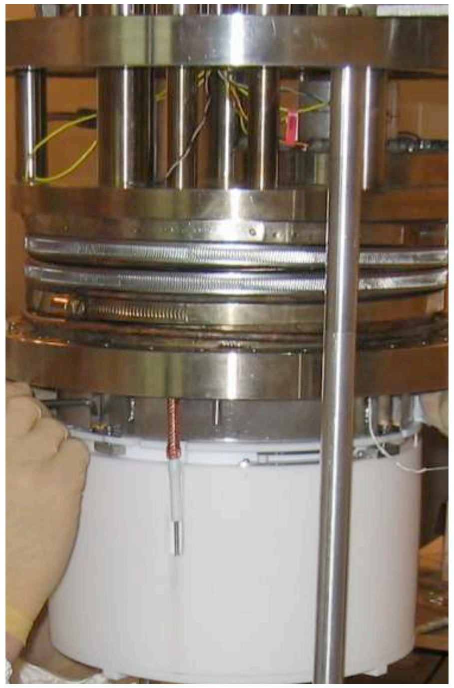


DARWIN collaboration, JCAP 1611 (2016) 017

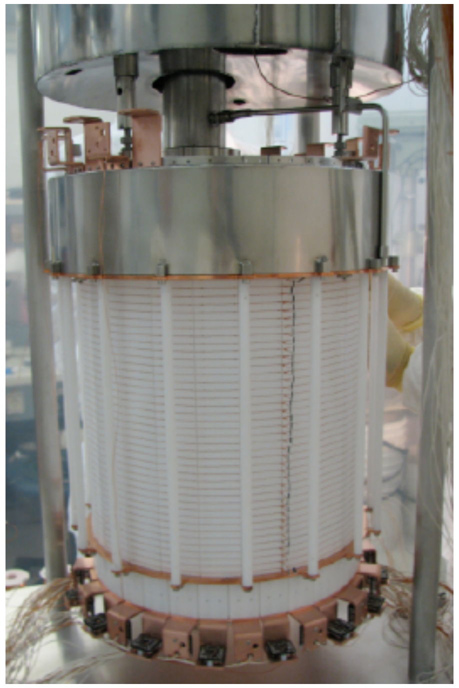
Alternative designs and photosensors under consideration

BENCHMARK: THE XENON LEGACY AT LNGS

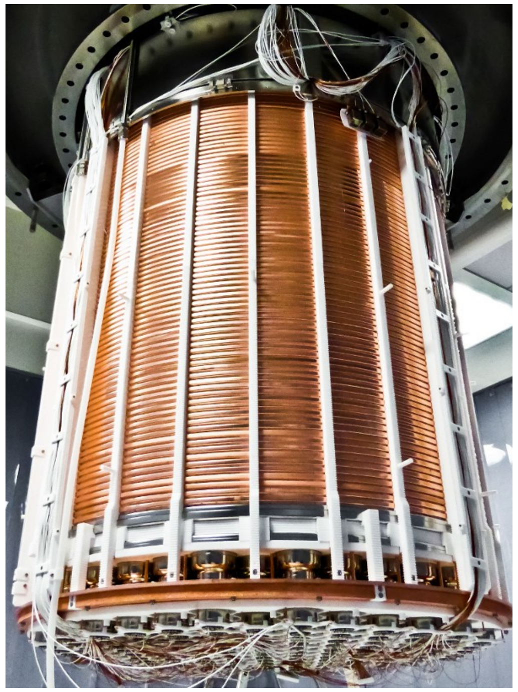
XENON10



XENON100

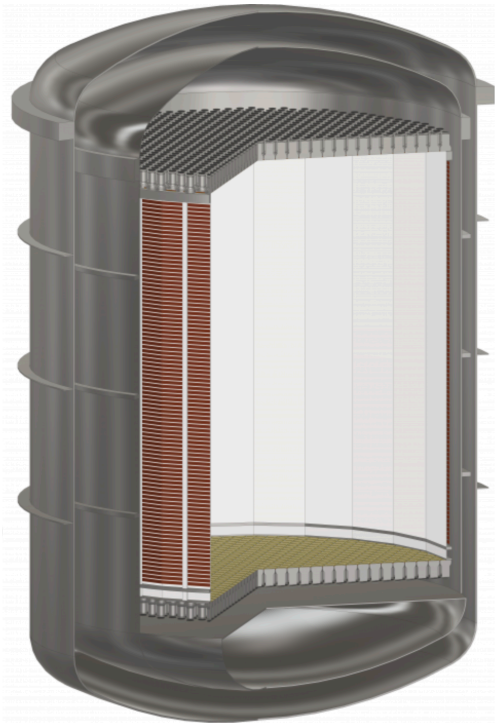


XENON1T



XENONnT

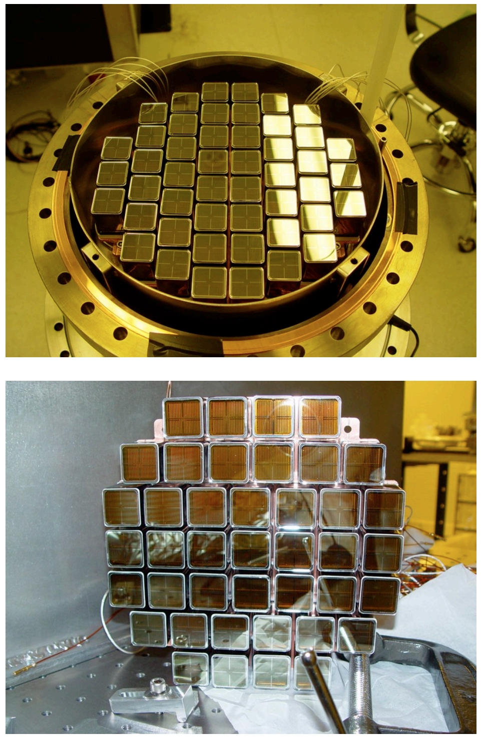
DARWIN



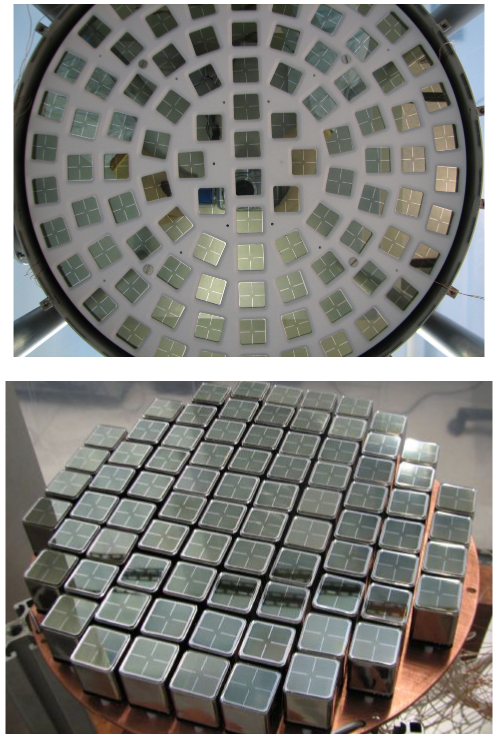
2005-2007	2008-2016	2012-2018	2020-2025	2027–
15 kg	161 kg	3200 kg	8400 kg	50 tonnes
15 cm	30 cm	96 cm	150 cm	260 cm
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2	~10^{-49} cm^2

BENCHMARK: THE XENON LEGACY AT LNGS

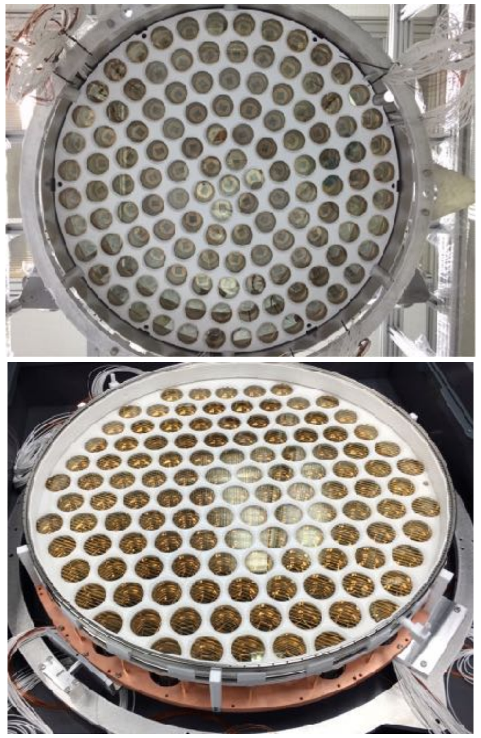
XENON10



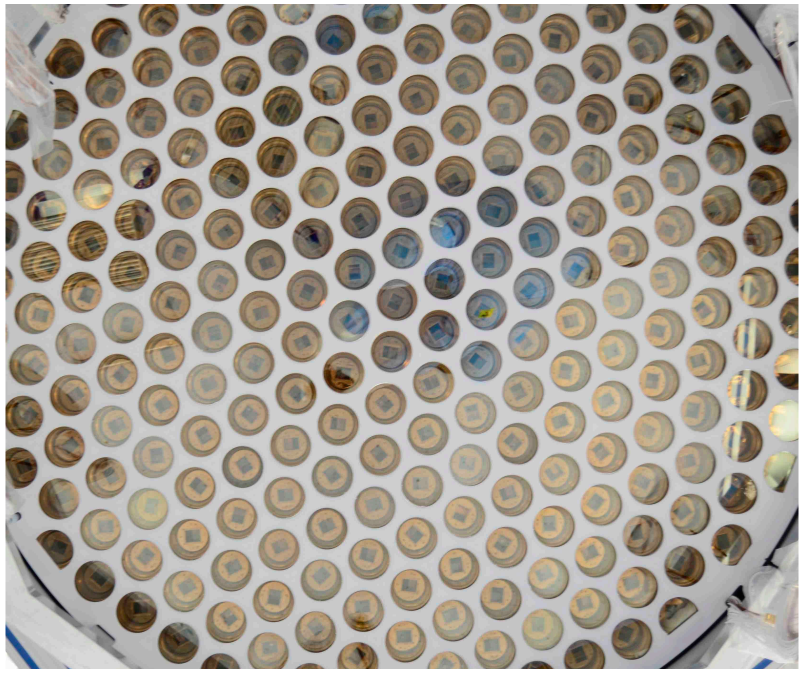
XENON100



XENON1T



XENONnT



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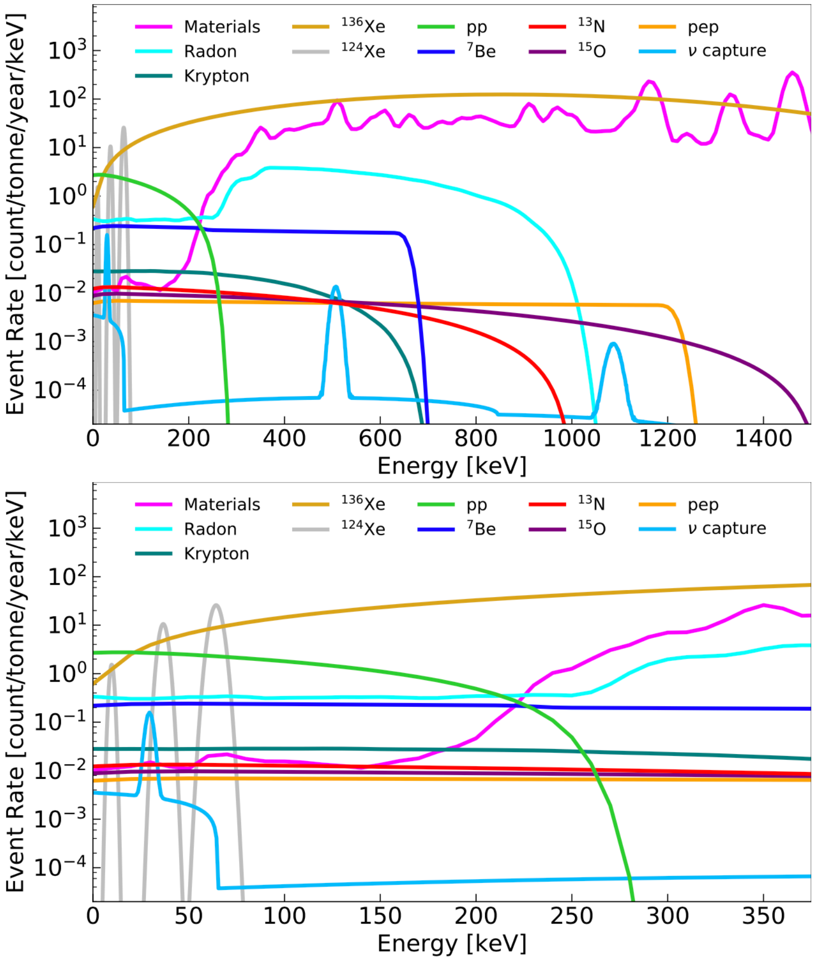
DARWIN BACKGROUND GOAL AND MAIN SOURCES

- Goal: allow for "background-free" exposure of 200 t y for the DM search
- ER and NR backgrounds: to be limited by neutrino-induced events
  - ^{222}Rn in liquid xenon: goal is 0.1 μBq/kg (achieved ~ 6 μBq/kg in XENON1T, ~ 1.8 μBq/kg in LUX)
  - ^{nat}Kr: goal is 0.1 ppt (achieved < 26 ppq*)
  - ^{136}Xe, ^{137}Xe, ^{124}Xe ($T_{1/2}$ = 1.8 x 10^{22} y**)
  - Solar neutrinos (pp, ^{7}Be)
  - Radiogenic neutrons
  - Muon-induced neutrons
  - CEvNS (solar, atm neutrinos)



Example:

ER background at low energies (30 t fiducial)

DARWIN collaboration, arXiv: 2006.03114

*XENON collaboration, EPJ-C 77, 2017

**XENON collaboration, Nature 568, 2019

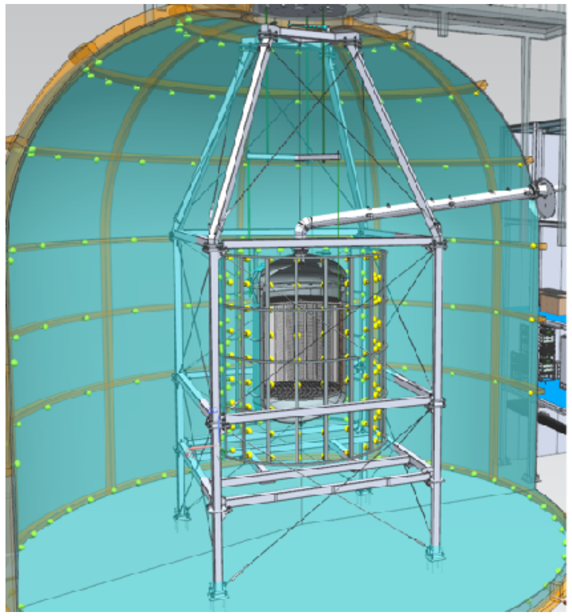
DARWIN PHYSICS PROGRAMME

DIRECT DARK MATTER DETECTION

SOLAR AXIONS

NEUTRINOLESS DOUBLE BETA DECAY ^{136}XE

DARWIN Collaboration, arXiv:2003.13407



GALACTIC ALPS, DARK PHOTONS

LOW-ENERGY SOLAR NEUTRINOS

DARWIN Collaboration, arXiv:2006.03114

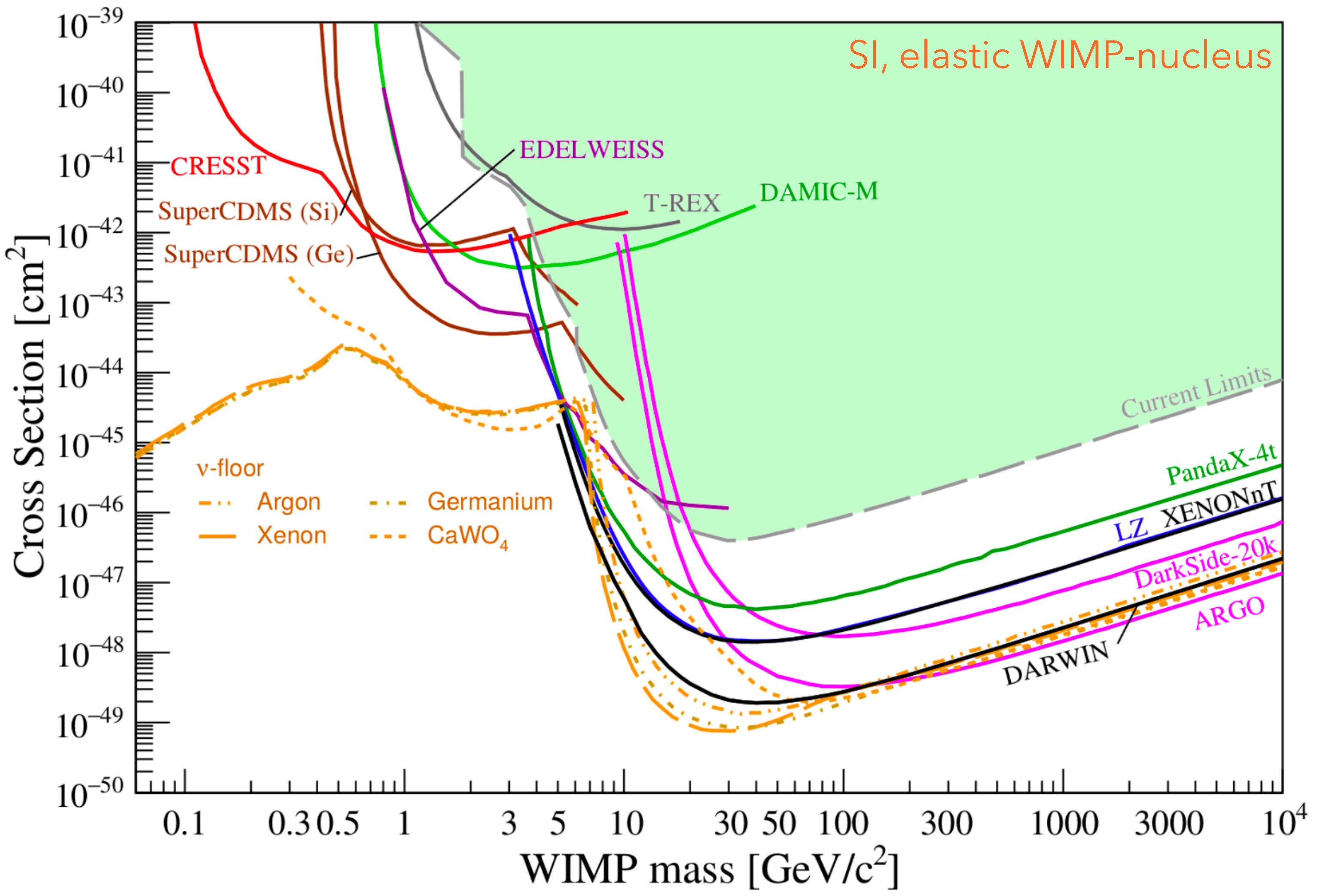
COHERENT NEUTRINO NUCLEUS SCATTERS

SUPERNOVA NEUTRINOS

darwin-observatory.org

DIRECT DARK MATTER DETECTION: WIMPS

- Probe SI elastic scattering: ^{124}Xe, ^{126}Xe, ^{128}Xe, ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe (26.9%), ^{134}Xe (10.4%), ^{136}Xe (8.9%)
- SD (+ inelastic) DM-nucleus scattering: ^{129}Xe (26.4%), ^{131}Xe (21.2%)



APPEC Dark Matter Report 2020

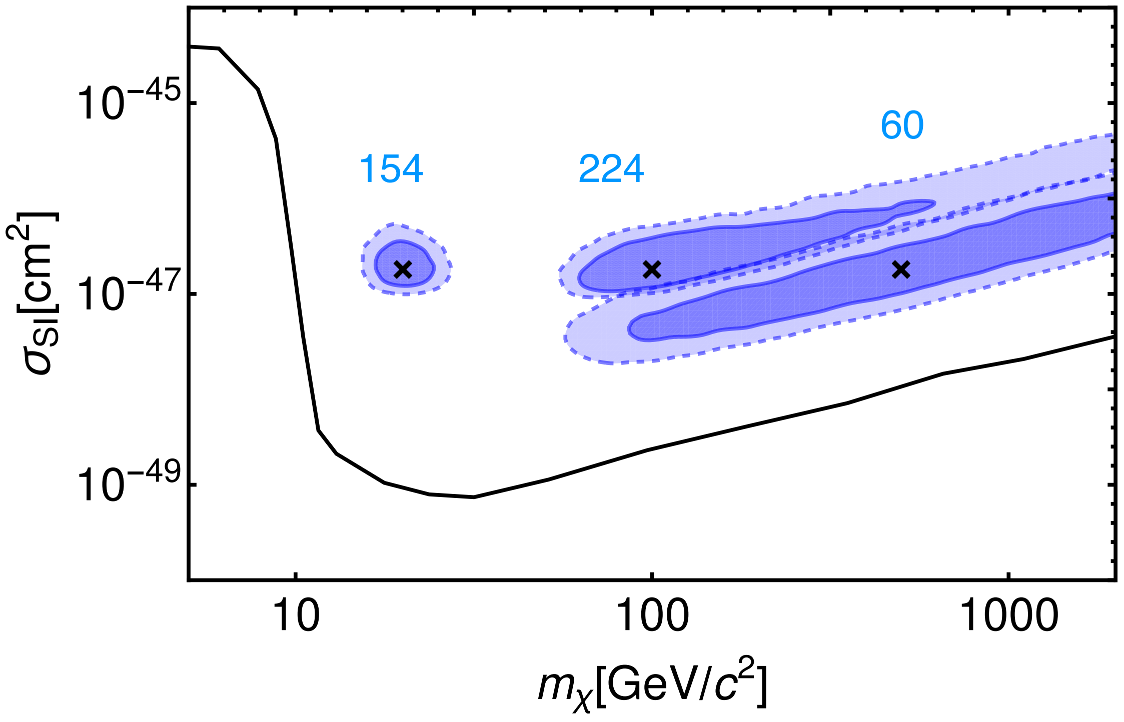
Preliminary

Committee Members:
Julien Billard[1], Mark Boulay[2], Susana Cebrián[3], Laura Covi[4], Giuliana Fiorillo[5], Anne Green[6], Joachim Kopp[7], Béla Majorovits[8], Kimberly Palladino[9], Federica Petricca[8], Leszek Roszkowski[10] (chair), Marc Schumann[11]

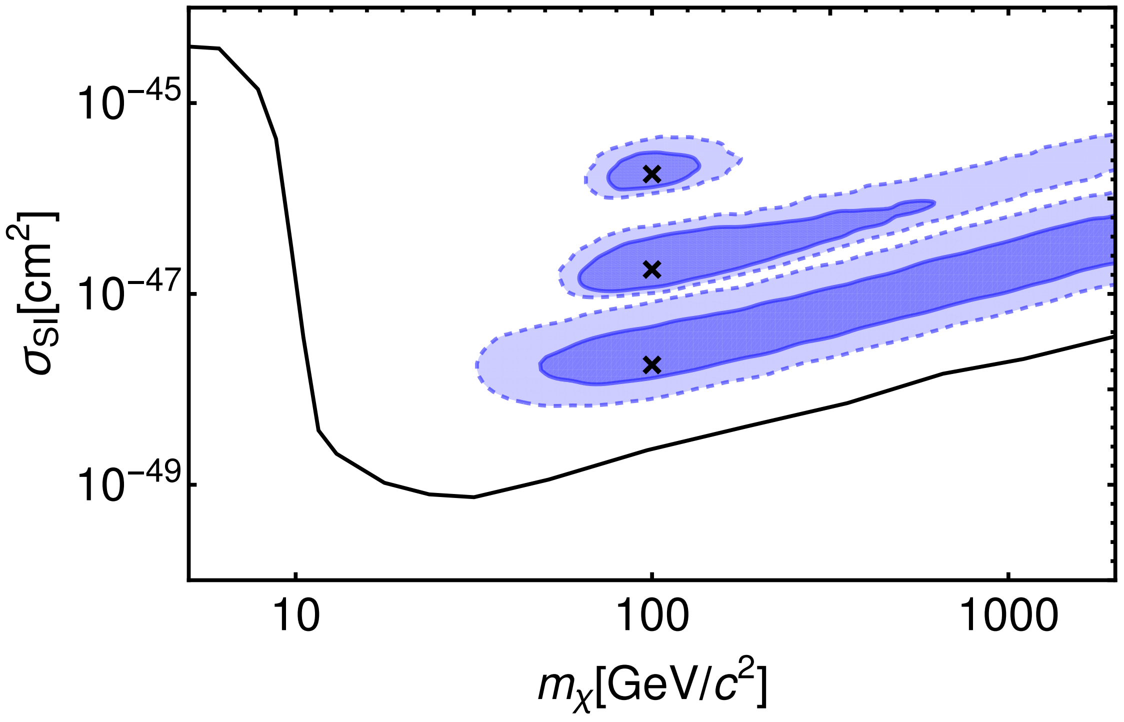
Assumptions for DARWIN: 30 t LXe in FV, 99.98% ER rejection (at 30% NR acceptance)

DIRECT DARK MATTER DETECTION: WIMP SPECTROSCOPY

- Capability to reconstruct the WIMP mass and cross section for various masses - here 20, 100, 500 GeV/c^2 - and cross sections



Exposure: 200 t y



Exposure: 200 t y

1 and 2 sigma credible regions after marginalising the posterior probability distribution over:

$$v_{esc} = 544 \pm 40\,\mathrm{km/s}$$

$$v_0 = 220 \pm 20\,\mathrm{km/s}$$

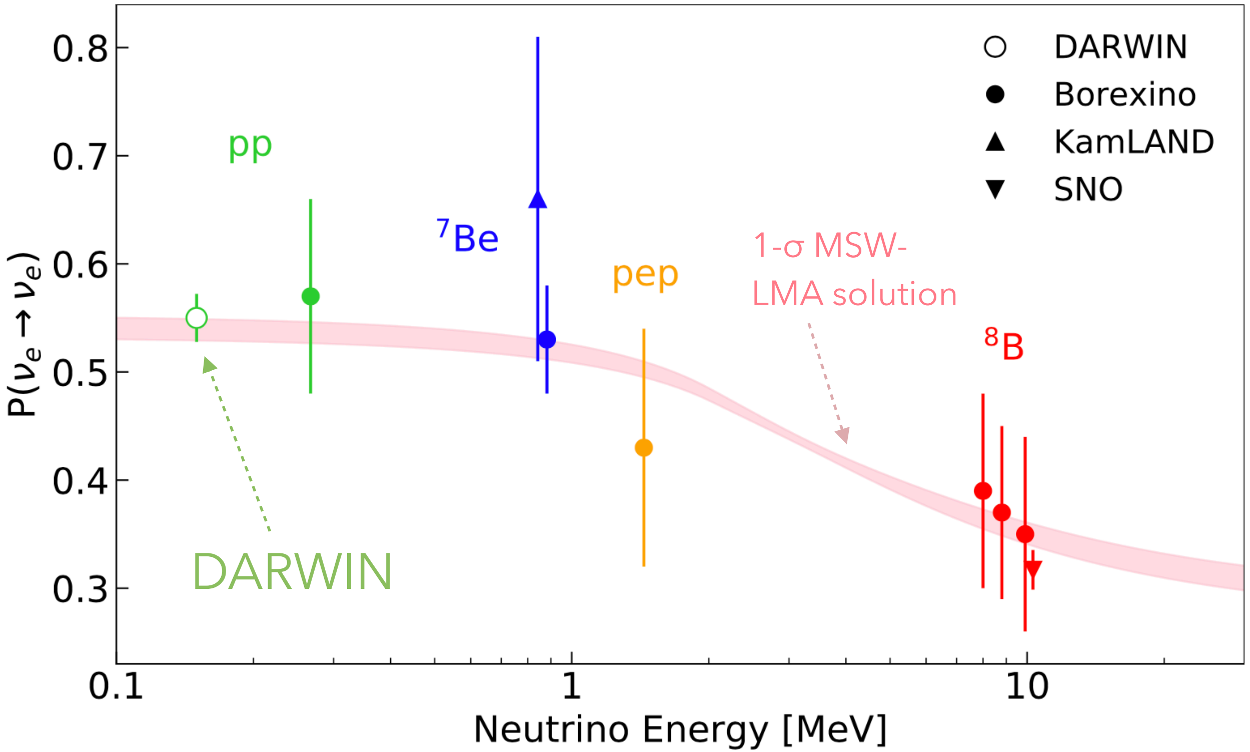
$$\rho_\chi = 0.3 \pm 0.1\,\mathrm{GeV/cm^3}$$

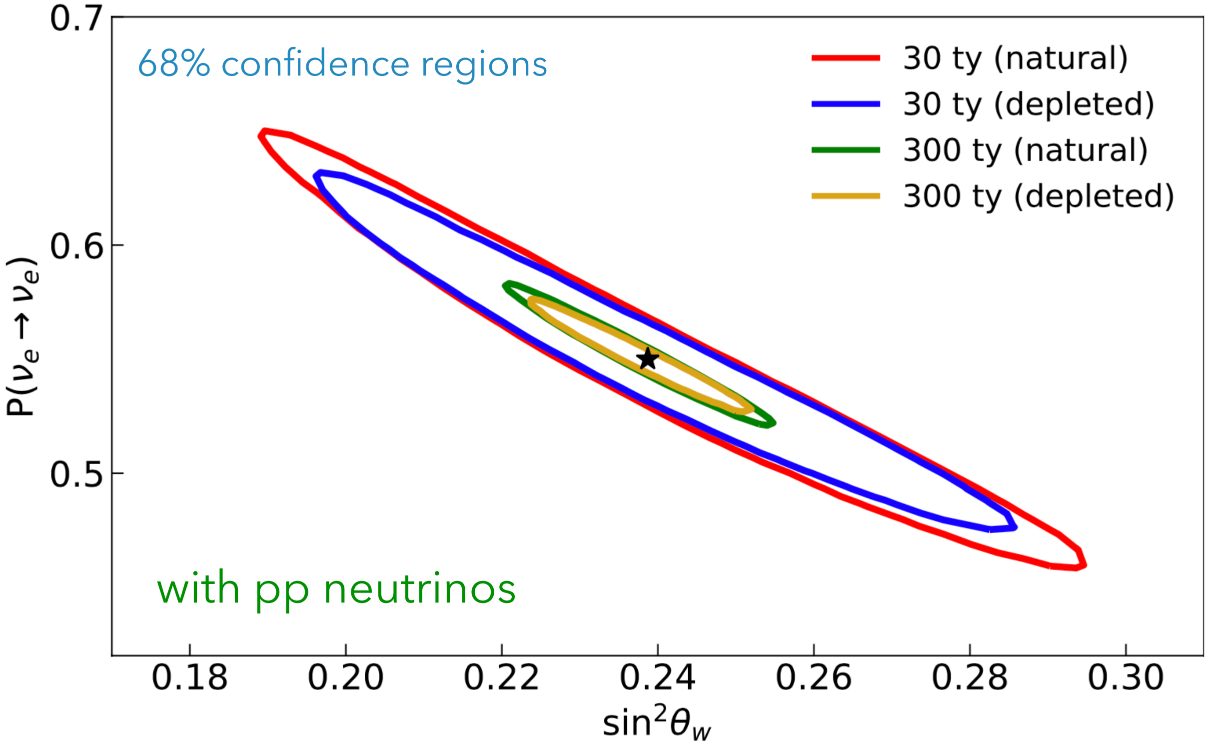
Update: Newstead et al., PRD D 88, 076011 (2013)

SOLAR NEUTRINOS $\nu + e^- \to \nu + e^-$

- Real-time measurement: 365 events/(t y) from pp ν and 140 events/(t y) from ^{7}Be ν (above 1 $\mathrm{keV_{ee}}$)
- pp-flux measurement: 0.15% statistical precision with 300 t y exposure (sub-percent after 10 t y)
- Measurement of ν_e survival probability & weak mixing angle < 300 keV

$$P(\nu_e \to \nu_e)$$

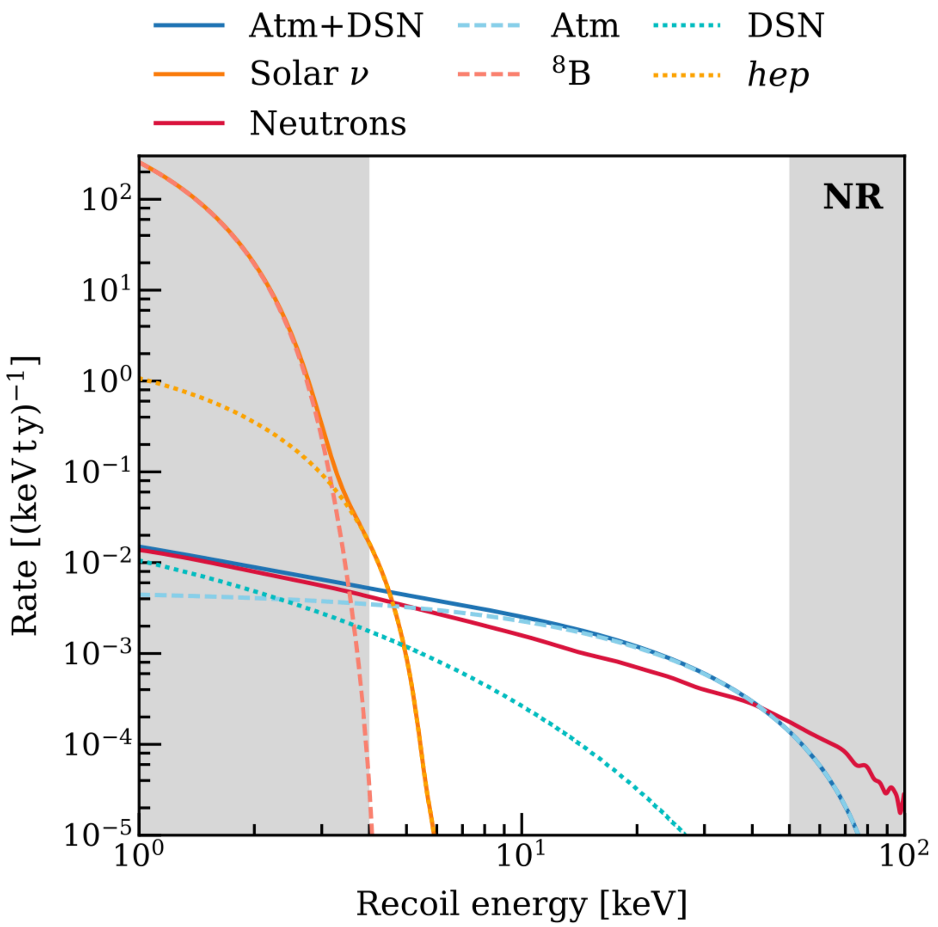




DARWIN collaboration, arXiv: 2006.03114

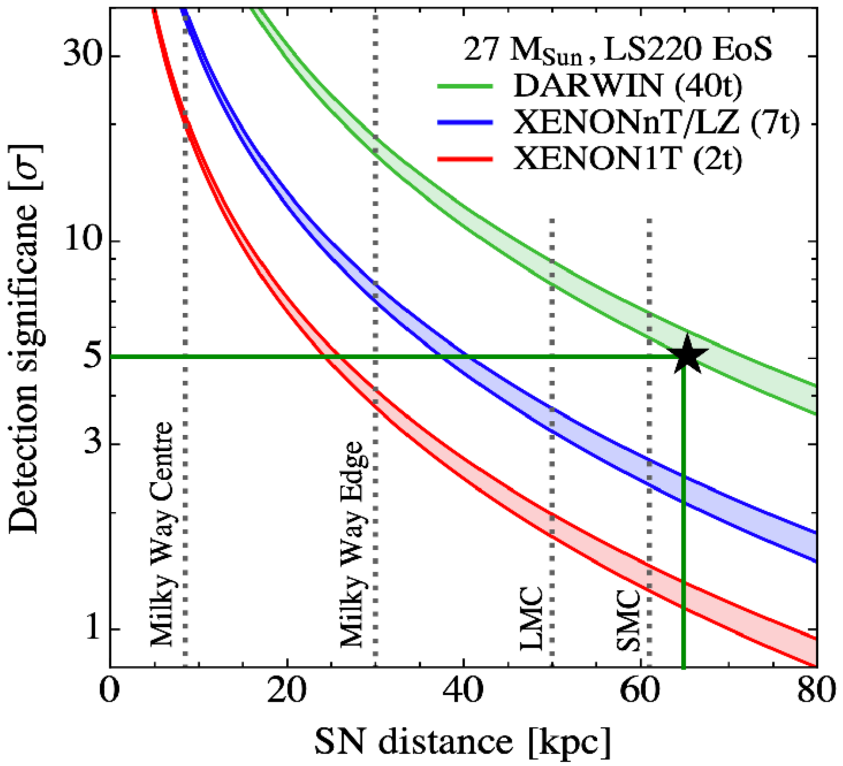
COHERENT NEUTRINO NUCLEUS SCATTERS

- Detect solar ^{8}B neutrinos: 90 events for $E_{th} > 1$ keV$_{nr}$ (however ~negligible above 4 keV$_{nr}$)
- Detect supernova neutrinos, sensitive to all neutrino flavours:
    - ~ 700 events from SN with 27 M_{solar} @ 10 kpc
- Planned participation in SNEWS network



XENON collaboration, arXiv:2007.08796

Signal integrated from [0, 7] s



R. Lang et al., PRD 94, 103009

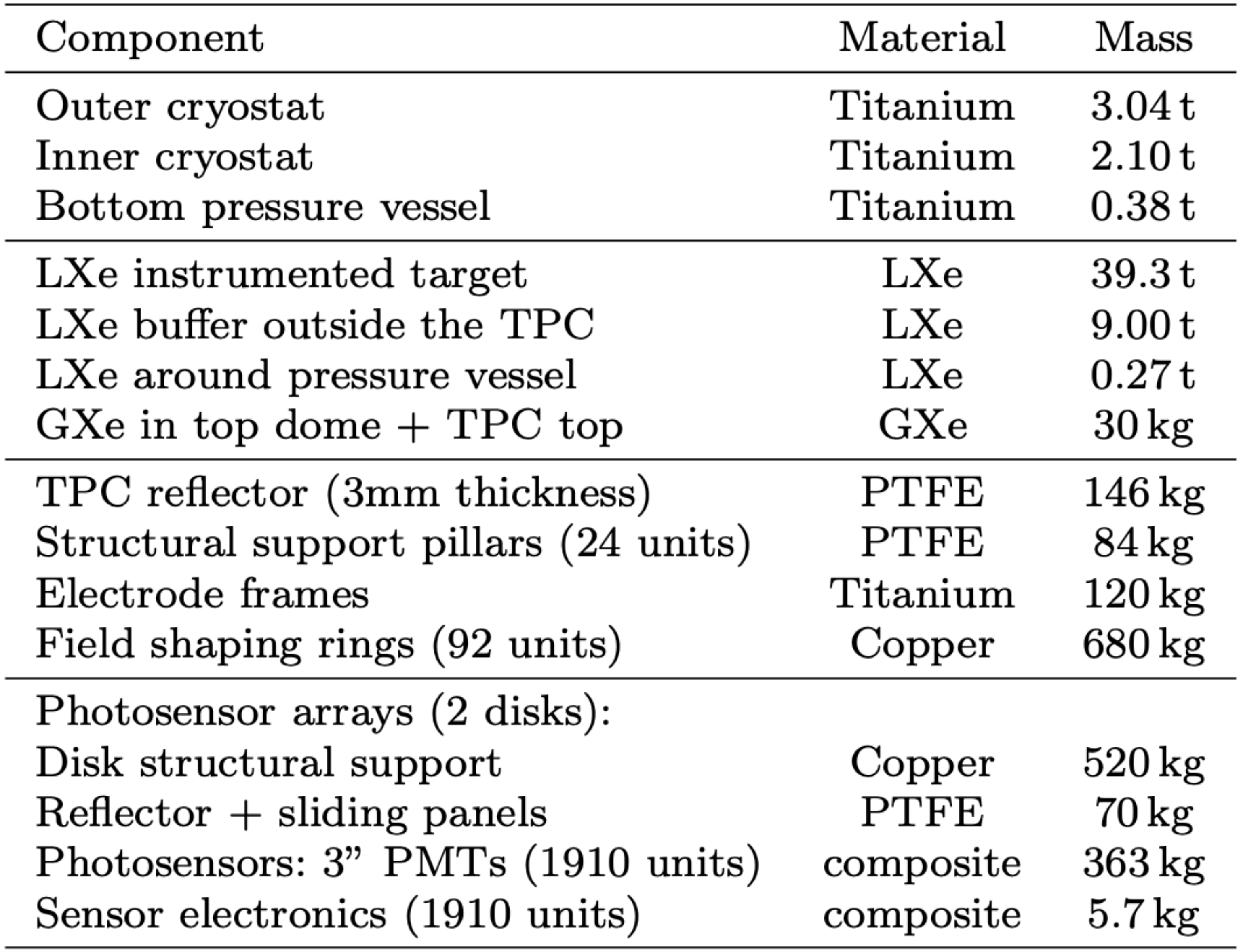
DOUBLE BETA DECAY IN DARWIN

- ^{136}Xe: excellent candidate
  - abundance in ^{nat}Xe: 8.9%, Q-value: (2457.83±0.37) keV*
- Total amount of ^{136}Xe in DARWIN: ~3.5 tonnes
- Expected (1-σ) energy resolution:
  - ~0.8% at 2.5 MeV, demonstrated by XENON1T
- Ultra-low background environment (^{222}Rn, ^{8}B neutrinos, ^{137}Xe from cosmogenic activation, 2νββ-decays)

*M. Redshaw et al., PRL 98, 2007: M(136Xe)-M(136Ba) =2457.83(37)

BACKGROUND SIMULATIONS FOR DOUBLE BETA STUDY

- Detailed detector model in Geant4



Component	Material	Mass
Outer cryostat	Titanium	3.04 t
Inner cryostat	Titanium	2.10 t
Bottom pressure vessel	Titanium	0.38 t
LXe instrumented target	LXe	39.3 t
LXe buffer outside the TPC	LXe	9.00 t
LXe around pressure vessel	LXe	0.27 t
GXe in top dome + TPC top	GXe	30 kg
TPC reflector (3mm thickness)	PTFE	146 kg
Structural support pillars (24 units)	PTFE	84 kg
Electrode frames	Titanium	120 kg
Field shaping rings (92 units)	Copper	680 kg
Photosensor arrays (2 disks):		
Disk structural support	Copper	520 kg
Reflector + sliding panels	PTFE	70 kg
Photosensors: 3” PMTs (1910 units)	composite	363 kg
Sensor electronics (1910 units)	composite	5.7 kg

Cryostat

Xenon

TPC components

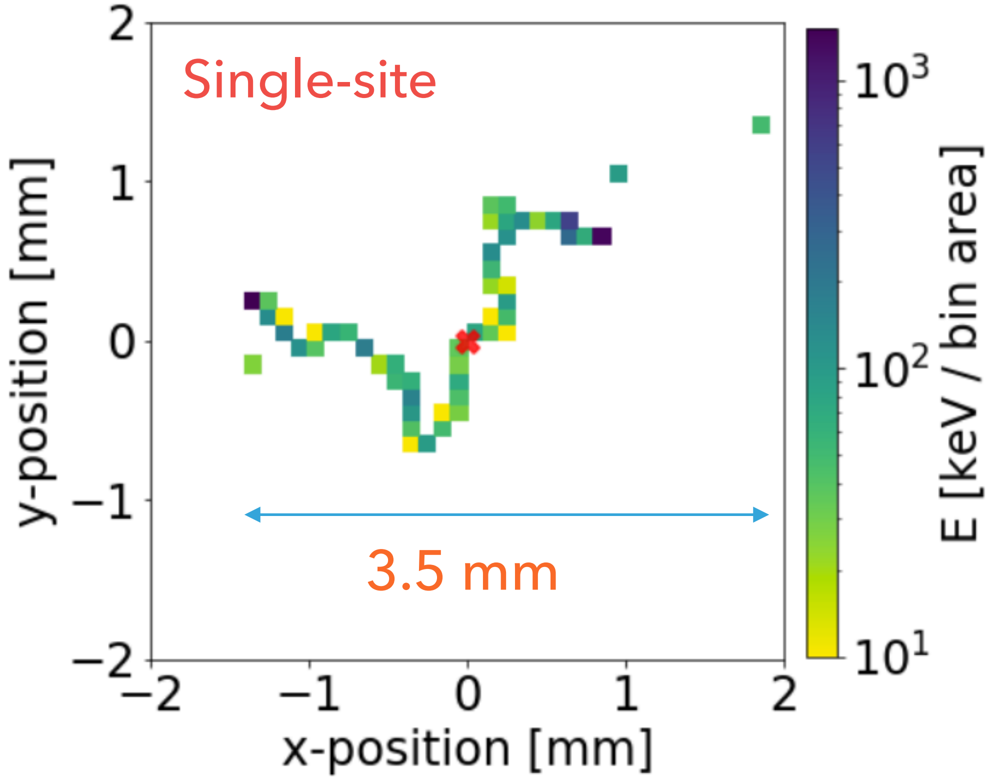
Photosensors and electronics

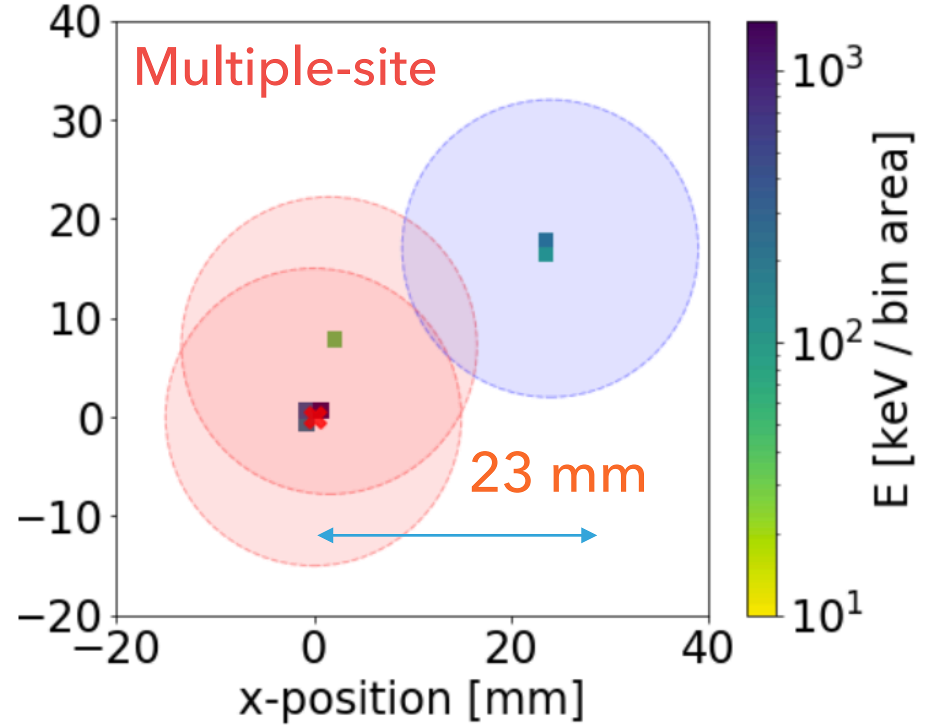
SIGNAL EVENTS IN LIQUID XENON

- Electrons thermalise within O(mm) => single-site topology
- Bremsstrahlung photons: may travel > 15mm (E>300 keV) => multi-site event
- Energy depositions: spatially grouped using density-based spatial clustering algorithm
  - New cluster, if distance to any previous $E_{dep} > \varepsilon$ (separation threshold)

Assumption: ε = 15 mm; 90% efficiency for ββ-events

2 e- back-to-back

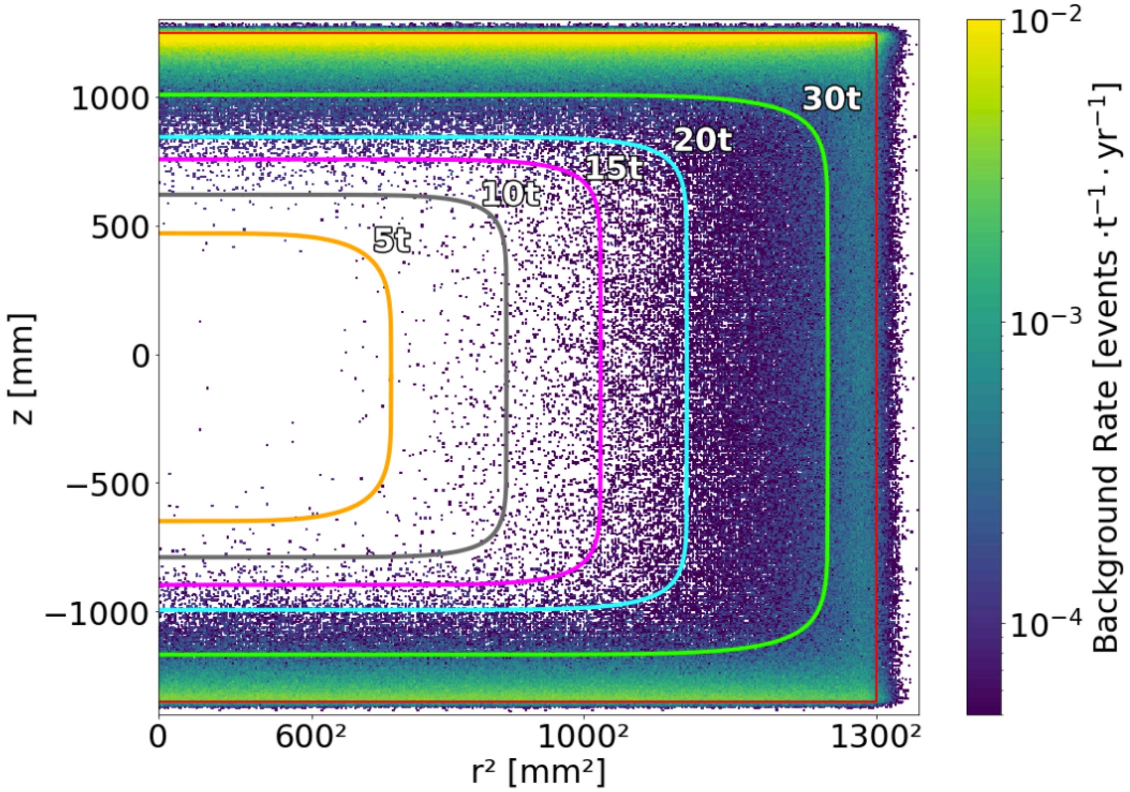




MAIN BACKGROUND COMPONENTS

- Intrinsic:
  - ^{8}B ν's, ^{137}Xe, 2νββ, ^{222}Rn
- Materials:
  - ^{238}U, ^{232}Th, ^{60}Co, ^{44}Ti
- FV cut: super-ellipsoidal

$$\left(\frac{z+z_0}{z_{max}}\right)^t + \left(\frac{r}{r_{max}}\right)^t < 1$$



100 y of DARWIN run time

External background events with energy deposits in the ROI [$Q_{\beta\beta}$ ± FWHM/2] = [2435 - 2481] keV

Material	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{60}Co	^{44}Ti
Titanium	mBq/kg	<1.6	<0.09	0.28	0.25	<0.02	<1.16
PTFE	mBq/kg	<1.2	0.07	<0.07	0.06	0.027	-
Copper	mBq/kg	<1.0	<0.035	<0.033	<0.026	<0.019	-
PMT	mBq/unit	8.0	0.6	0.7	0.6	0.84	-
Electronics	mBq/unit	1.10	0.34	0.16	0.16	<0.008	-

^{44}Ti: $T_{1/2}$ = 59 y, cosmogenic

Ti: LZ, Astrop. Phys., 96 (2017)

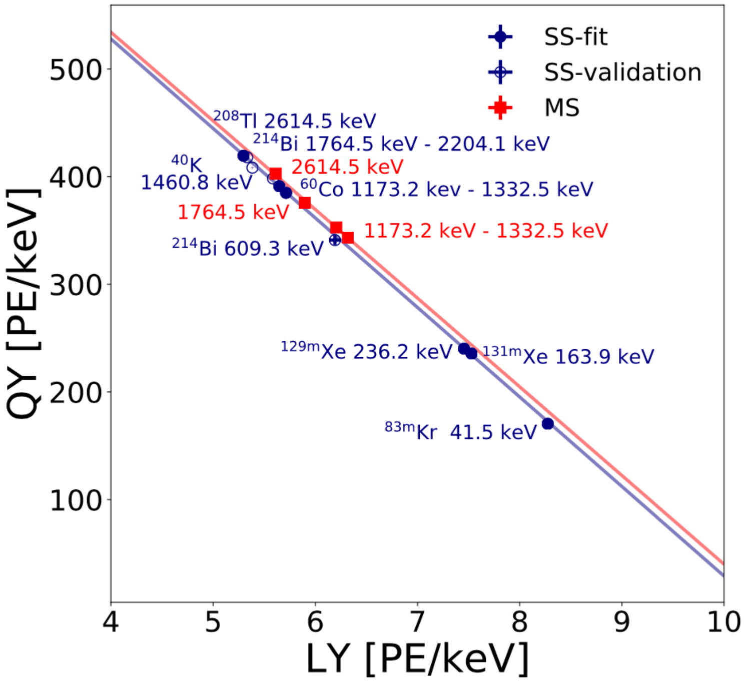
Other: XENON, EPJ-C 77 (2017)

ENERGY RESOLUTION

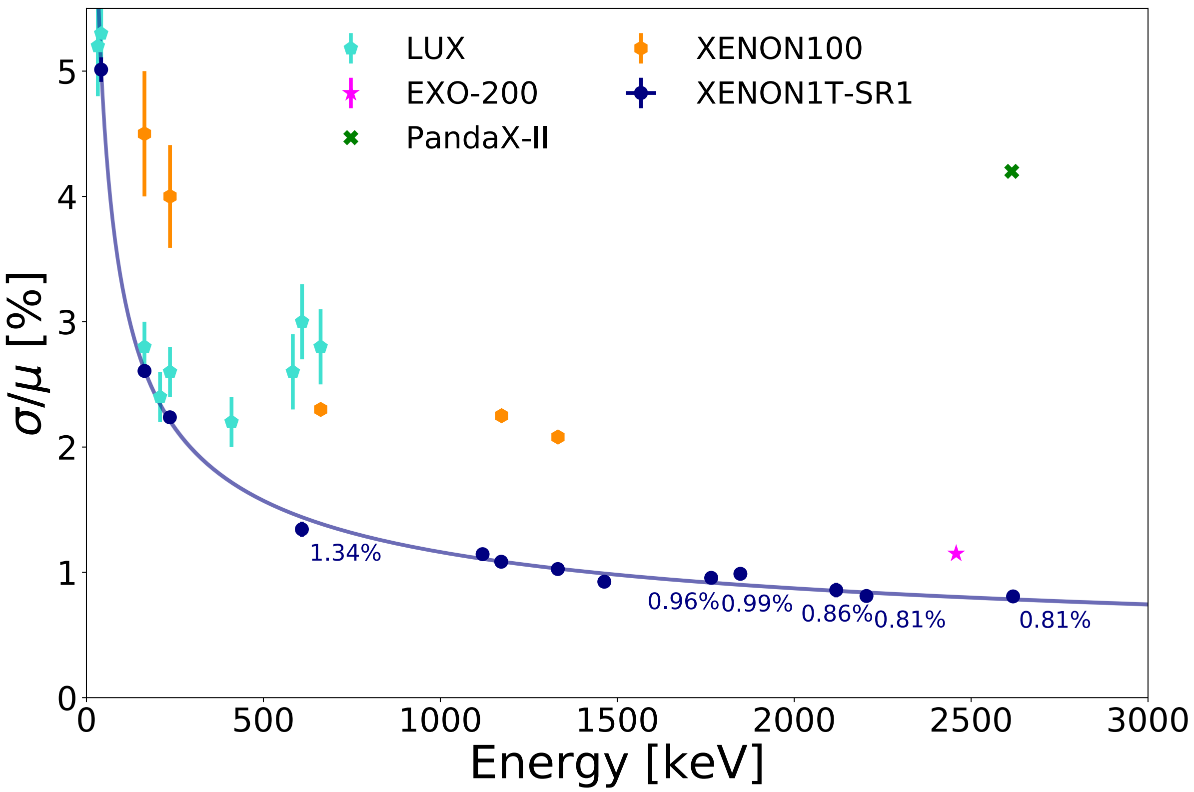
- Anti-correlation between light (S1) and charge (S2)
- Energy scale uses linear combination of S1 and S2
- Photon gain: g_1 (pe/photon), electron gain: g_2 (pe/electron)

$$E = (n_{ph} + n_e) \cdot W = \left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right) \cdot W$$

W-value = 13.7 eV



$$\frac{S2}{E} = \frac{g_2}{W} - \frac{g_2}{g_1}\frac{S1}{E}$$



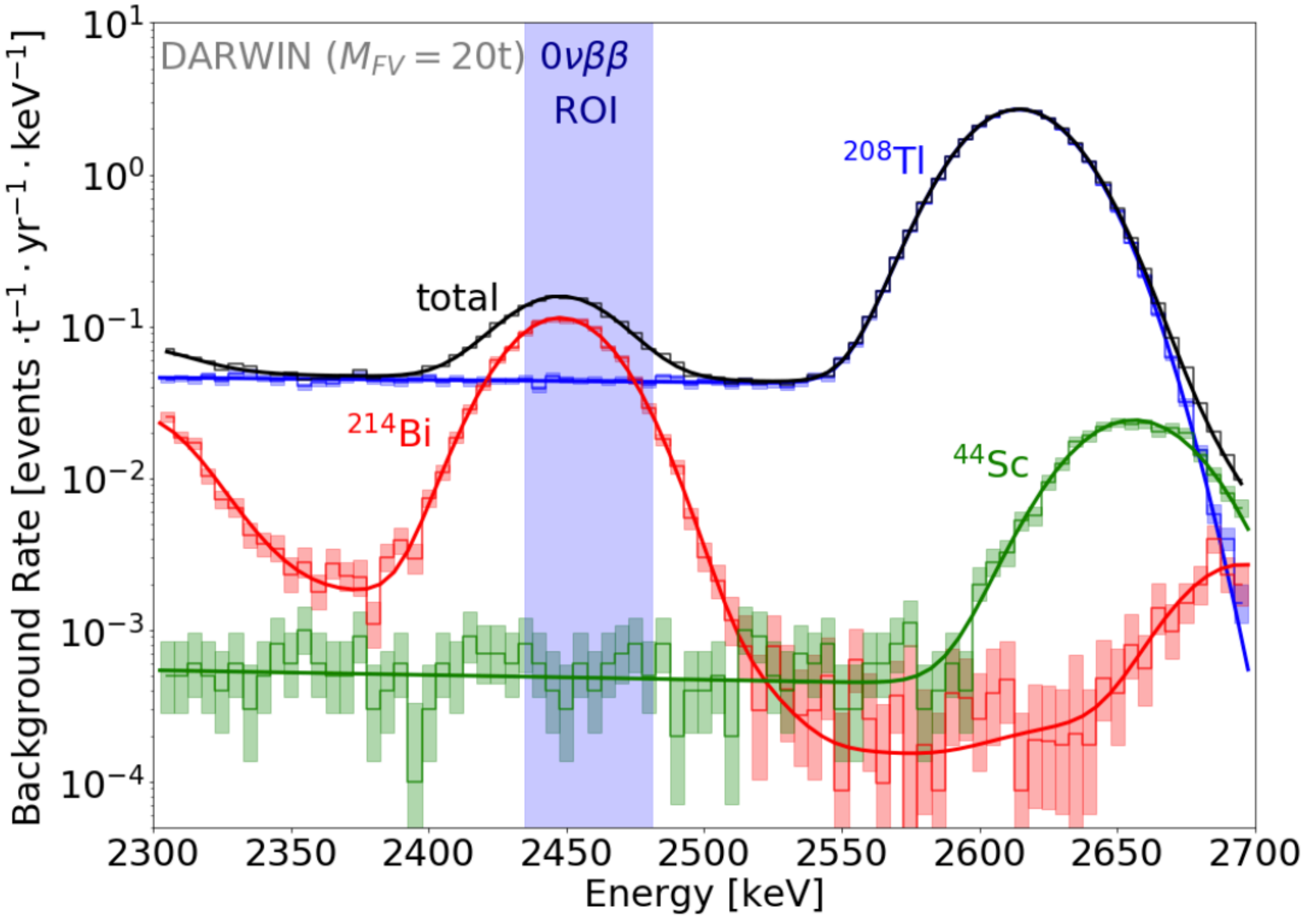
Example for XENON1T:

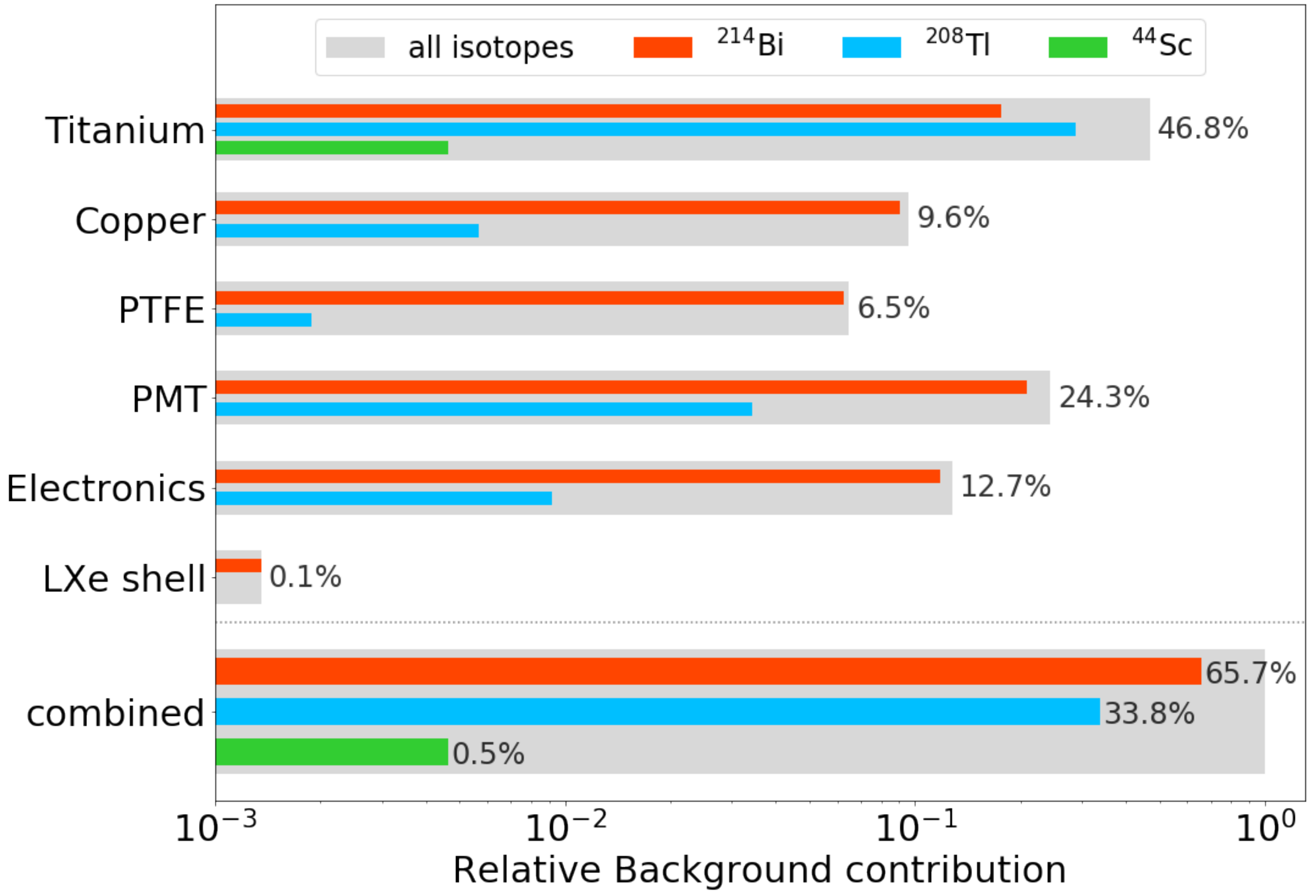
σ/E ≈ 0.8% at $Q_{\beta\beta}$

XENON collaboration, arXiv: 2003.03825, accepted in EPJ-C

EXTERNAL (MATERIAL) BACKGROUND

- ROI: [2435-2481] keV = FHWM around $Q_{\beta\beta}$
- ^{214B}Bi: γ at 2.45 MeV, ^{208}Tl, γ at 2.61 MeV; ^{44}Sc, γ at 2.66 MeV



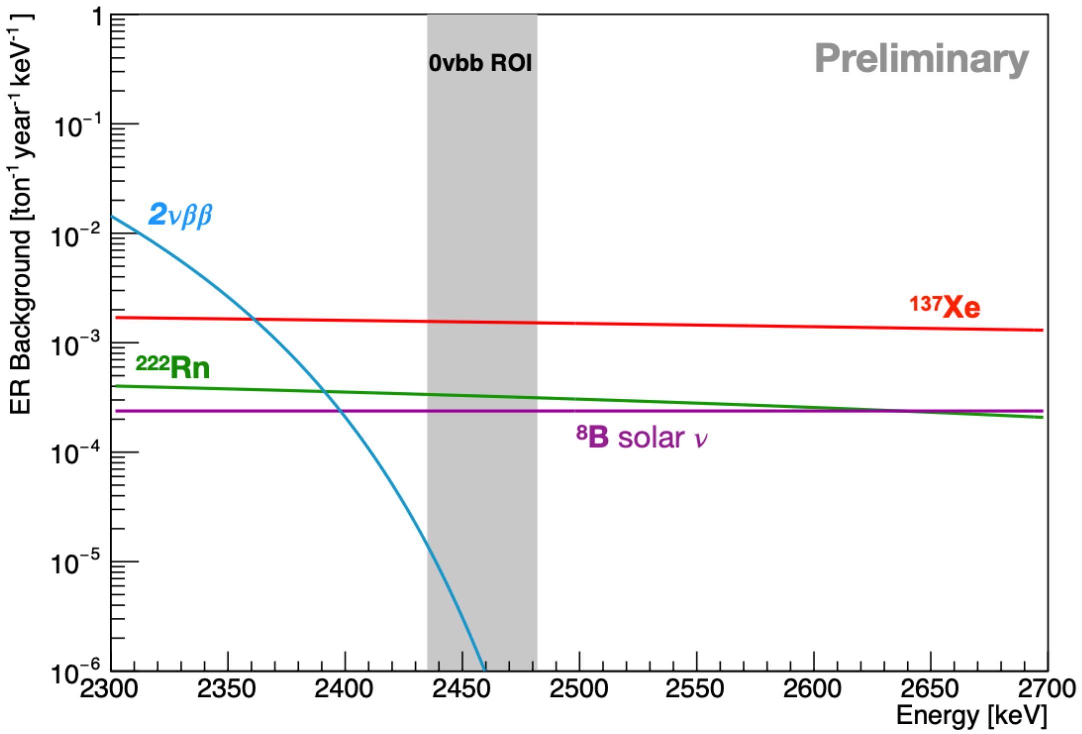


20 tones of LXe in fiducial volume

INTERNAL BACKGROUNDS

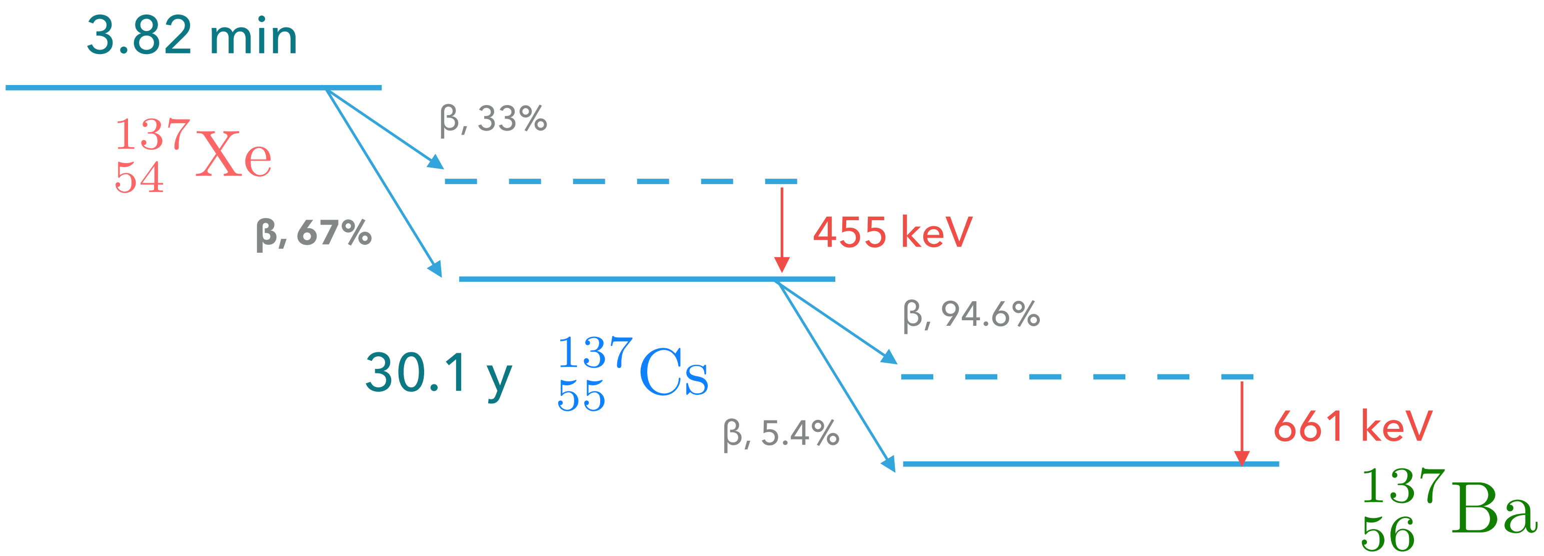
- ^{222}Rn in LXe:
  - 0.1μBq/kg, 99.8% BiPo tagging
- ^{8}B solar neutrinos
  - $\Phi_{ve} = (5.46 \pm 0.66) \times 10^6\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - $P_{ee} = 0.50$
- 2νββ-decay: subdominant
- ^{137}Xe: cosmogenic activation underground
  - n + ^{136}Xe -> ^{137}Xe

^{137}Xe: (6.9±0.4) atoms/(t y)



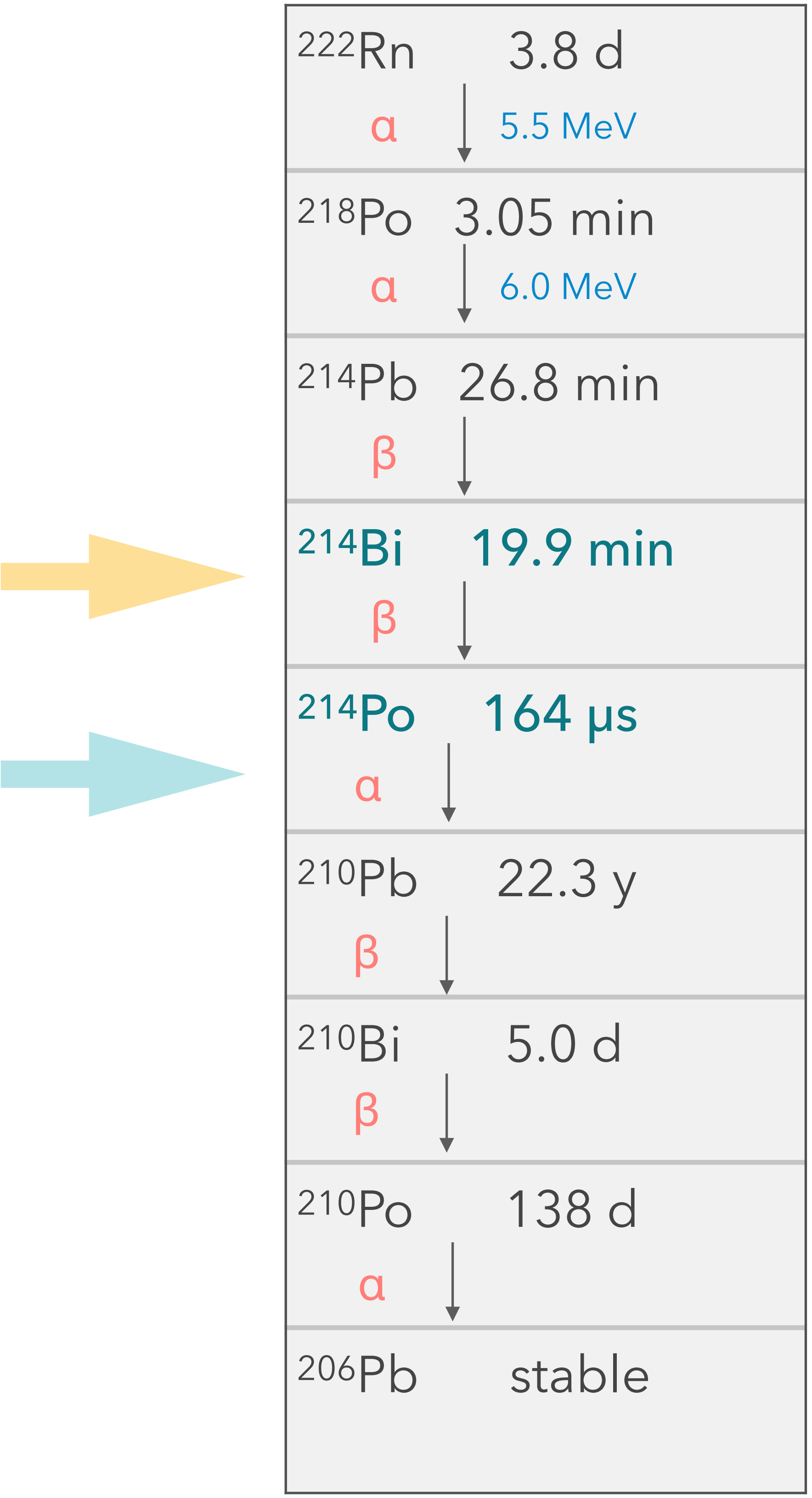
$T_{1/2}$ = 3.82 min

Q-value: 4173 keV



RADON BACKGROUND

- Assumption:
  - 0.1 µBq/kg ^{222}Rn (cryogenic distillation + material selection)
- Problematic:
  - ^{214}Bi decay, Q-value = 3.27 MeV, "naked" β-decay without γ emission: 19.1% BR
- ^{214}Po:
  - α-decay with short half-life, $T_{1/2}$ =164.3 µs => active veto for ^{214}Bi-decays
- Assumption:
  - 99.8% BiPo tagging efficiency

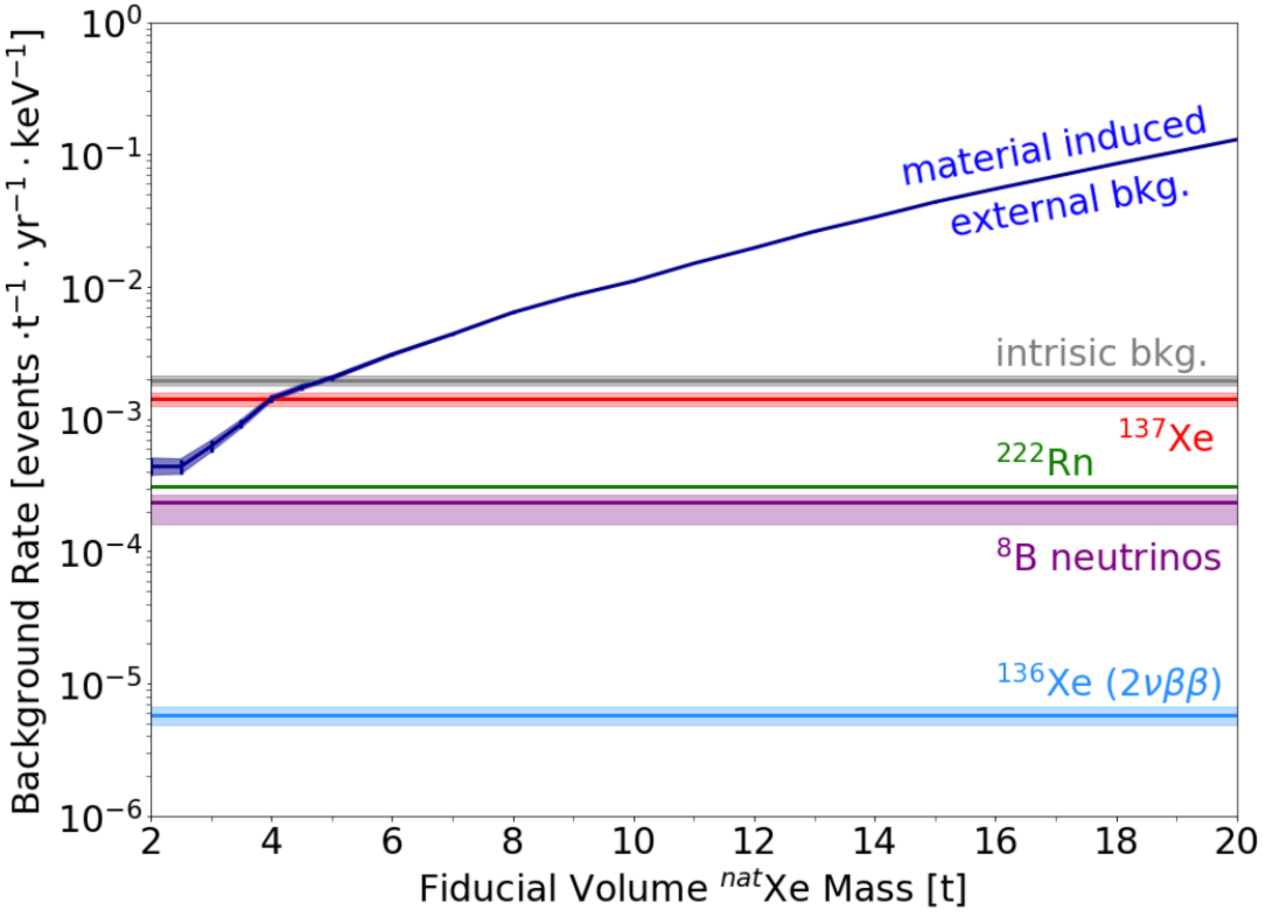


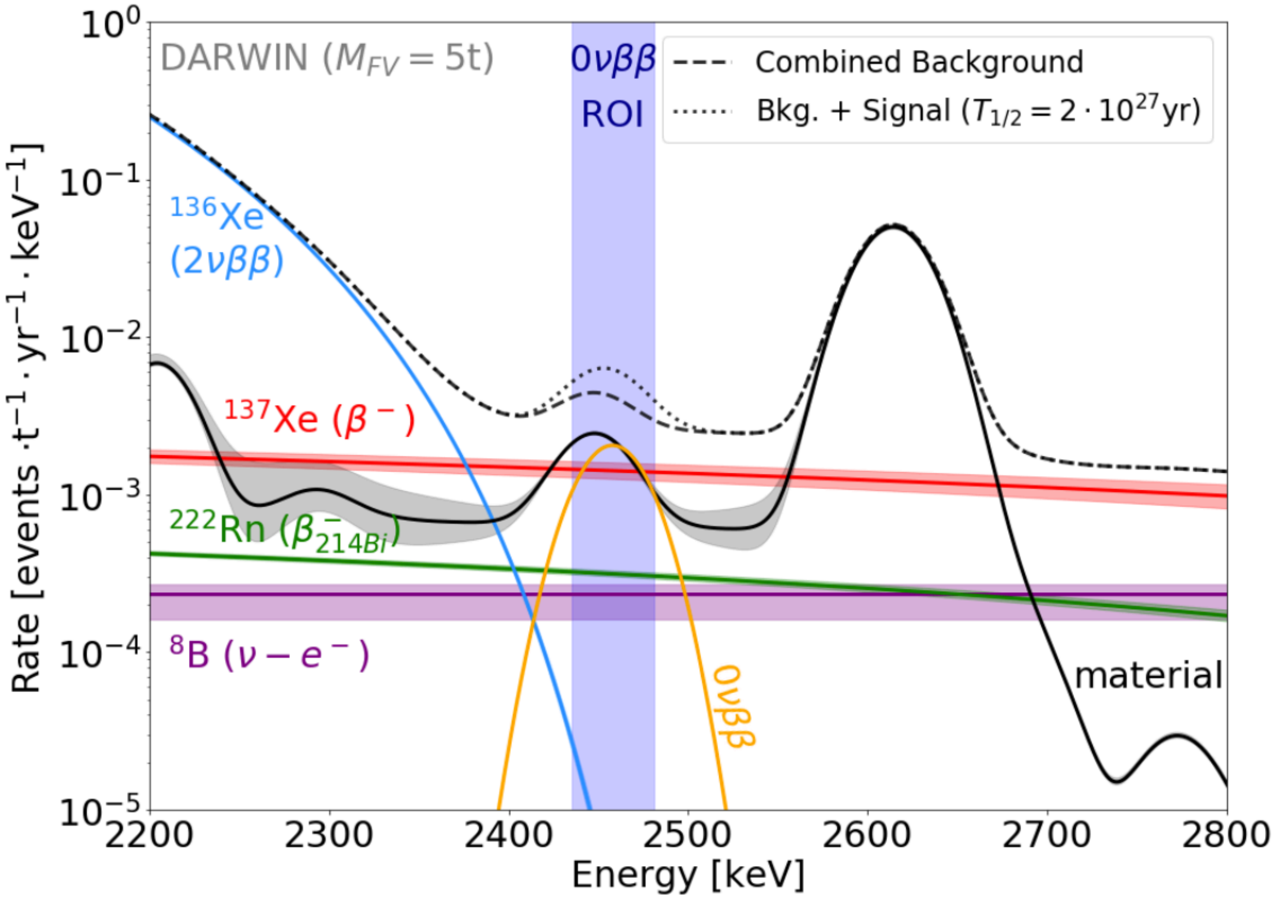
^{222}Rn	3.8 d	α	5.5 MeV
^{218}Po	3.05 min	α	6.0 MeV
^{214}Pb	26.8 min	β	
^{214}Bi	19.9 min	β	
^{214}Po	164 µs	α	
^{210}Pb	22.3 y	β	
^{210}Bi	5.0 d	β	
^{210}Po	138 d	α	
^{206}Pb	stable		

MATERIAL + INTRINSIC BACKGROUND

- ROI: [2435-2481] keV = FHWM around $Q_{\beta\beta}$
- ^{137}Xe: β-decay with Q=4173 keV, $T_{1/2}$=3.82 min (via n-capture on ^{136}Xe)

Signal: $T_{1/2}$ = 2 x 10^{27} y



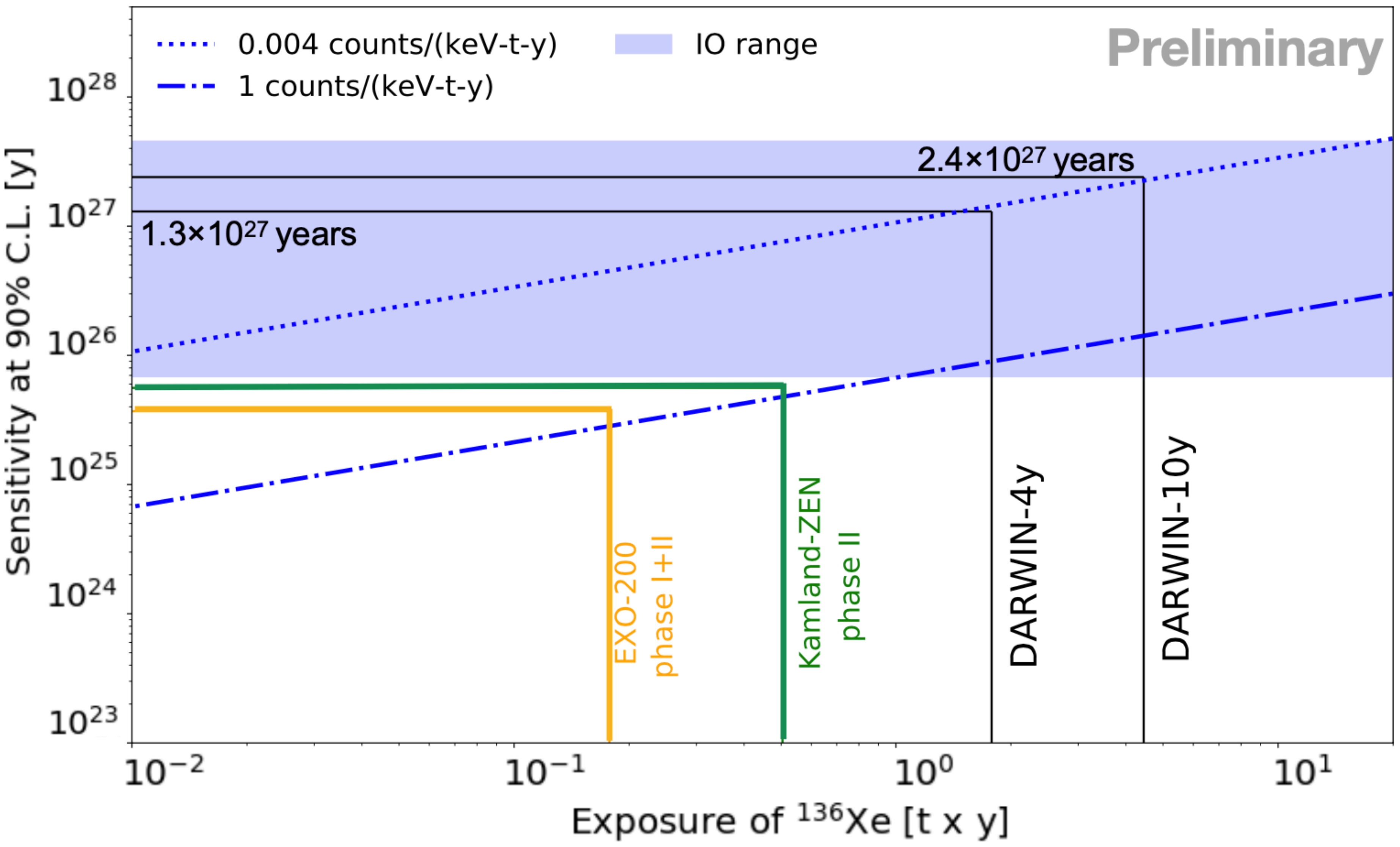


Rate versus fiducial mass

Rate in 5 tonnes fiducial region (0.45 t ^{136}Xe)

DOUBLE BETA DECAY SENSITIVITY

- Profile likelihood analysis, baseline $T_{1/2}$ sensitivity:
- 2.4 x 10^{27} y for 5 t fiducial mass x 10 y exposure (90% CL)

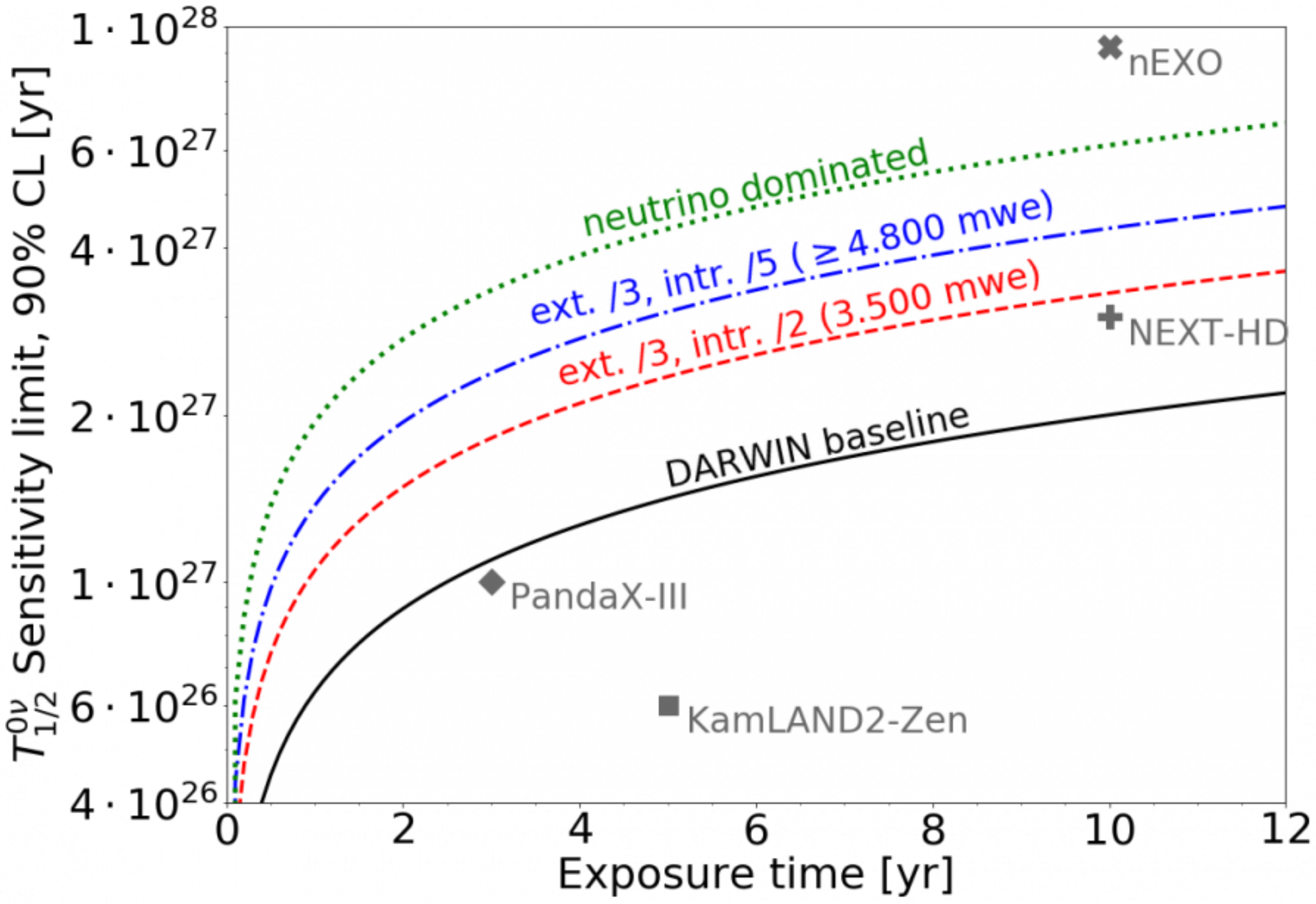


Discovery potential:

1.1 x 10^{27} y at 3-σ

ROOM FOR IMPROVEMENT?

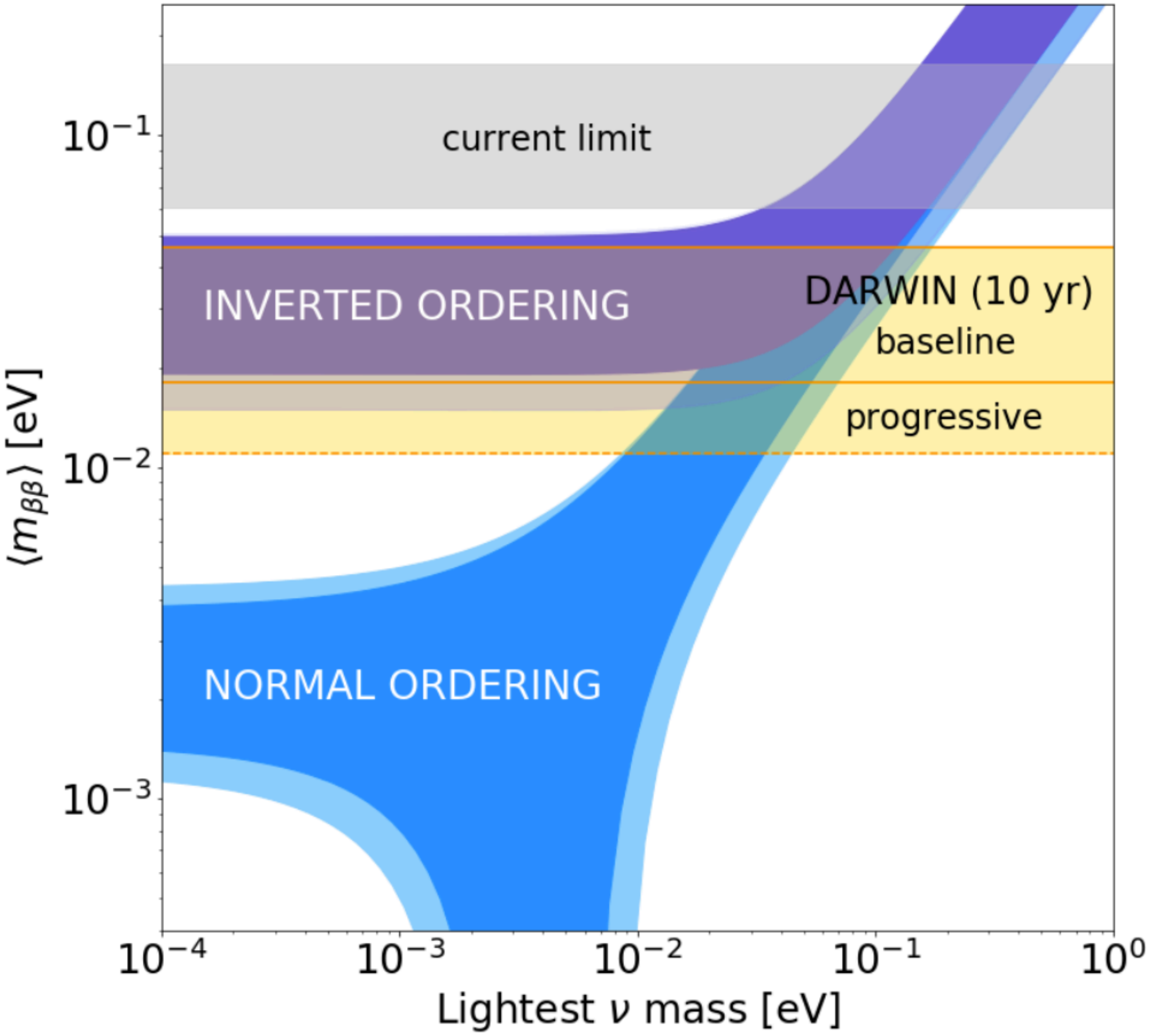
- Reduce external backgrounds
  - SiPMs, cleaner materials & electronics
- Reduce internal background
  - Time veto for ^{137}Xe, deeper lab, BiPo tagging
- Improve signal/background discrimination; resolution…



DARWIN could reach ~6 x 10^{27} y sensitivity

ROOM FOR IMPROVEMENT?

- Reduce external backgrounds
  - SiPMs, cleaner materials & electronics
- Reduce internal background
  - Time veto for ^{137}Xe, deeper lab, BiPo tagging
- Improve signal/background discrimination; resolution…



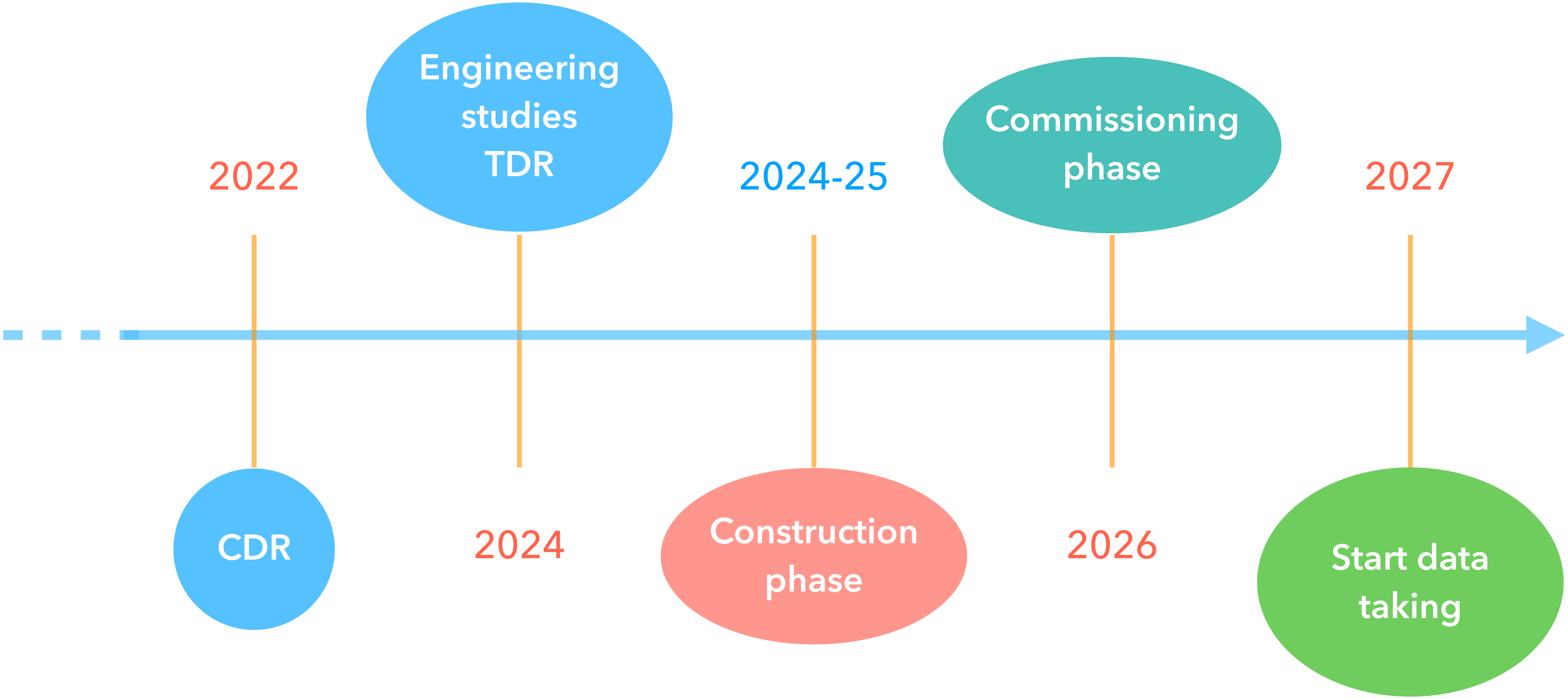
Baseline: $m_{\beta\beta}$ = (18 – 46) meV

Progressive: $m_{\beta\beta}$= (11– 28) meV

PROJECT OVERVIEW

- 30 groups from 12 countries , working towards CDR and TDR
- R&D and design on several aspects:
  - Detector including cryostat & TPC
  - Light and charge sensors & readout
  - Backgrounds (incl. Rn/Kr removal, materials) & veto
  - LXe procurement, storage, purification & cryogenics
  - Xenon properties and calibration of 50 t detector

DARWIN TIMESCALE



2022

CDR

2024

Engineering studies TDR

2024-25

Construction phase

2026

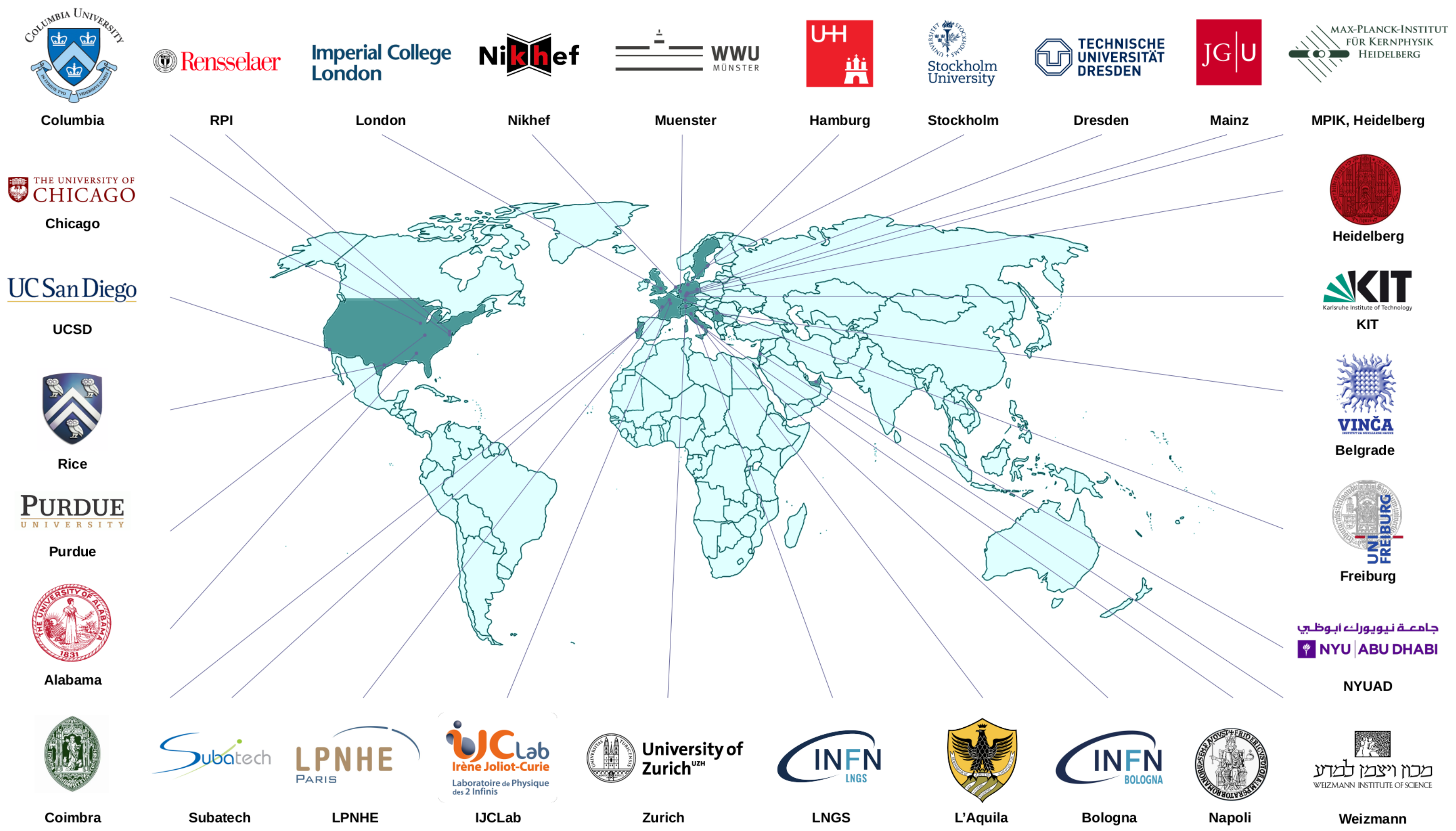
Commissioning phase

2027

Start data taking

THE DARWIN COLLABORATION

- About 170 members from 30 institutions in Europe, USA and Asia
- Latest groups to join: University of Alabama (Igor Ostrovsky), University of Hamburg (Belina von Krosigk), University of L'Aquila (Alfredo Ferella), University of Naples (Michele Iacovacci)



LNGS, December 2019

DETECTOR PROTOTYPES

European Research Council

Established by the European Commission

- Two large-scale demonstrators in construction (z & x-y) supported by ERC grants
- These also offer test platforms for the entire collaboration
- Smaller TPCs are operated at various institutions

Universität Zürich^{UZH}

Test e^- drift over 2.6 m (purification, high-voltage)

UNI FREIBURG

Test electrodes and homogeneity of extraction field

DETECTOR PROTOTYPES

European Research Council
Established by the European Commission

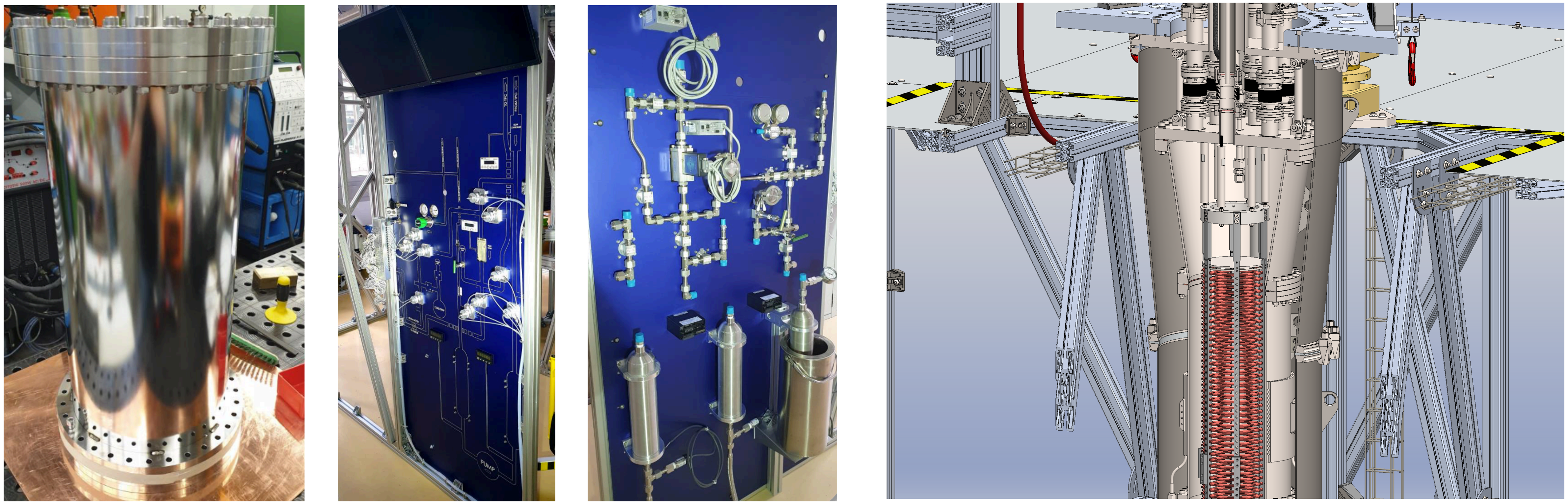
Test e- drift over 2.6 m (purification, high-voltage)

Test electrodes and homogeneity of extraction field

DETECTOR PROTOTYPES: XENOSCOPE

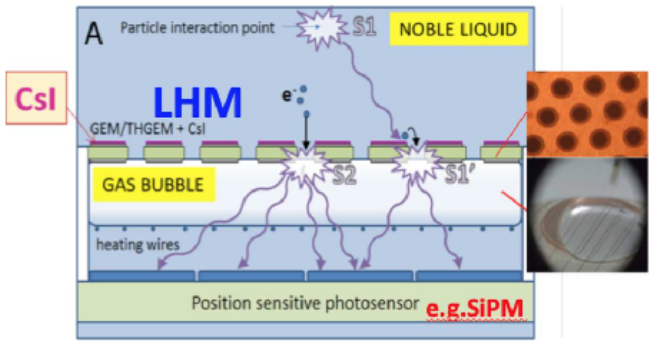
European Research Council
Established by the European Commission

- Under construction at UZH, first commissioning in late 2020
- Support structure, gas system, cryostat, cooling tower, electrical system, etc completed
- HV feed-through, TPC and purity monitor under design/construction
- Goals: test 200 V/cm drift field, 100 slpm purification speed, measure e^- cloud diffusion, etc

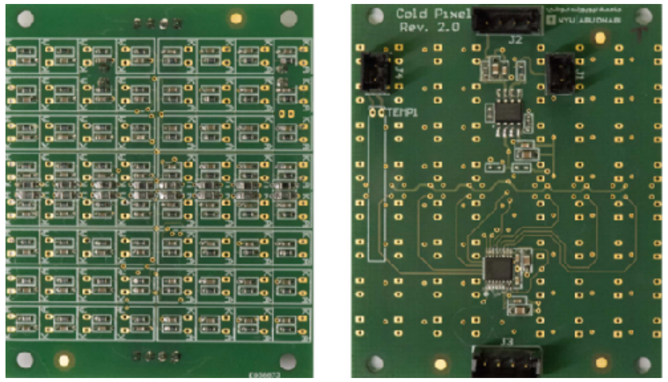


LIGHT AND CHARGE SENSORS AND READOUT

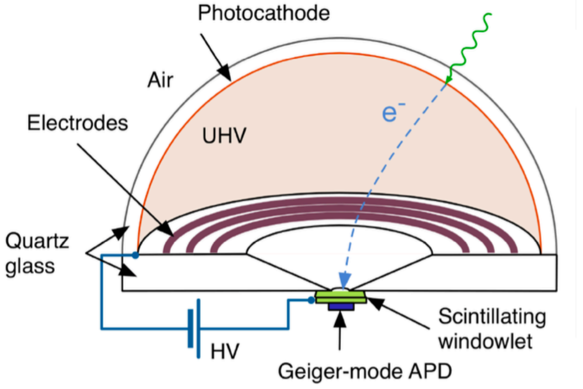
- Test alternative to PMTs: e.g., ABALONE (hybrid photosensor), VUV-SiPMs (FBK, Hamamatsu)
- Develop cryogenic electronics for SiPMs; develop cryogenic digital SiPMs
- Bubble-assisted Liquid Hole Multipliers: local vapour bubble underneath GEM-like perforated electrode in LXe



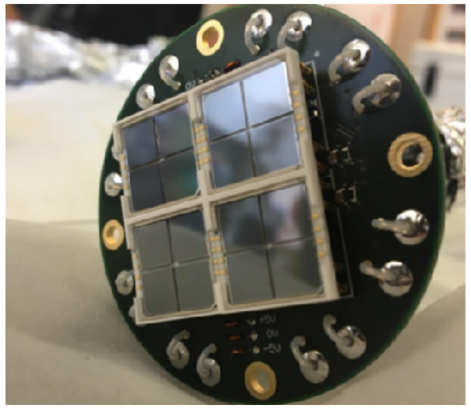
Liquid hole multipliers
E. Erdal, 2018 JINST 13, 2018



Cryogenic preamp for SiPMs, F. Arneodo et al., NIM 936, 2019



ABALONE, D. Ferenc et al., NIM 954, 2020

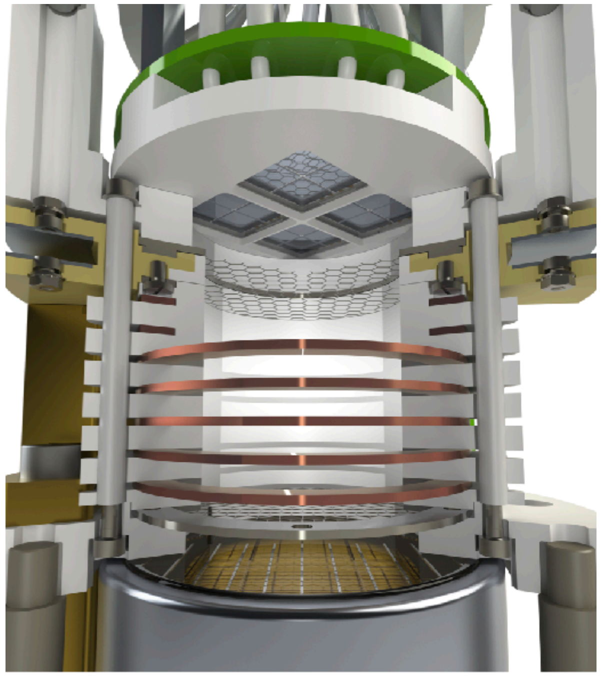


Hamamatsu SiPM arrays in two-phase TPC, LB et al., EPJ-C 80, 2020

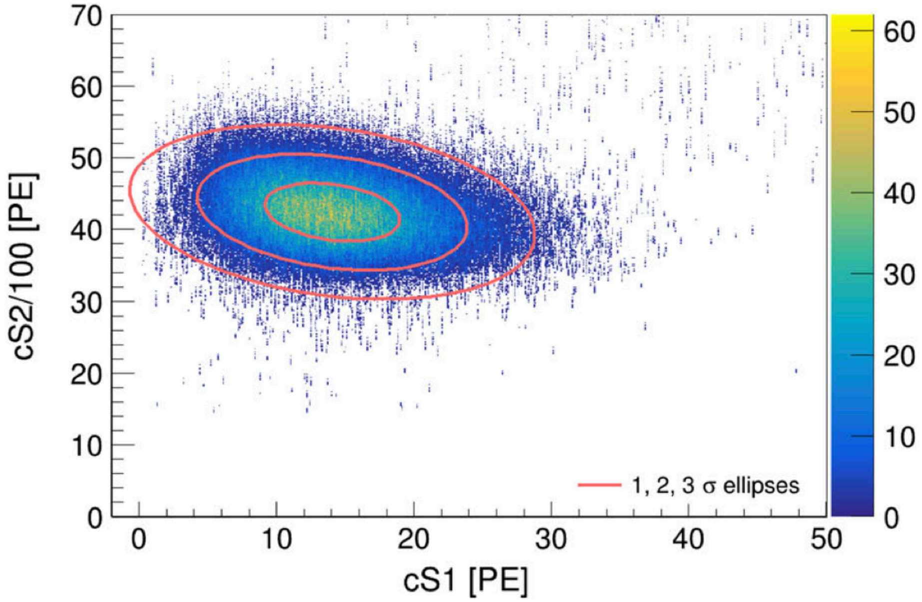
LIGHT AND CHARGE SENSORS AND READOUT

- Test VUV-sensitive SiPMs as potential replacement for PMTs
- First Xe-TPC with SiPM in top array at UZH
- Characterisation with ^{37}Ar and ^{83m}Kr sources

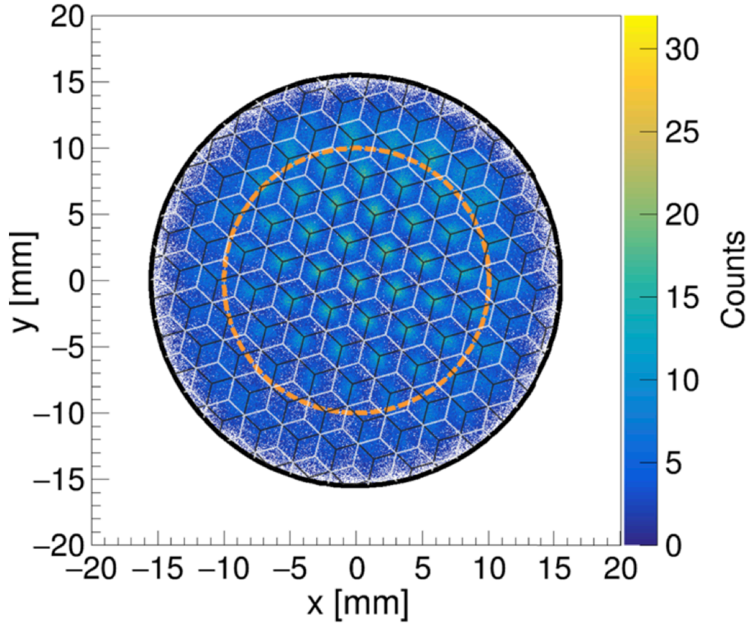
Characterisation with ^{37}Ar source



Upgrade of Xurich-II (LB et al., EPJ-C 80, 2020 and EPJ- C 78, 2018)



S2 versus S1 for the 2.82 keV ^{37}Ar line (K-shell, 90.2% BR)



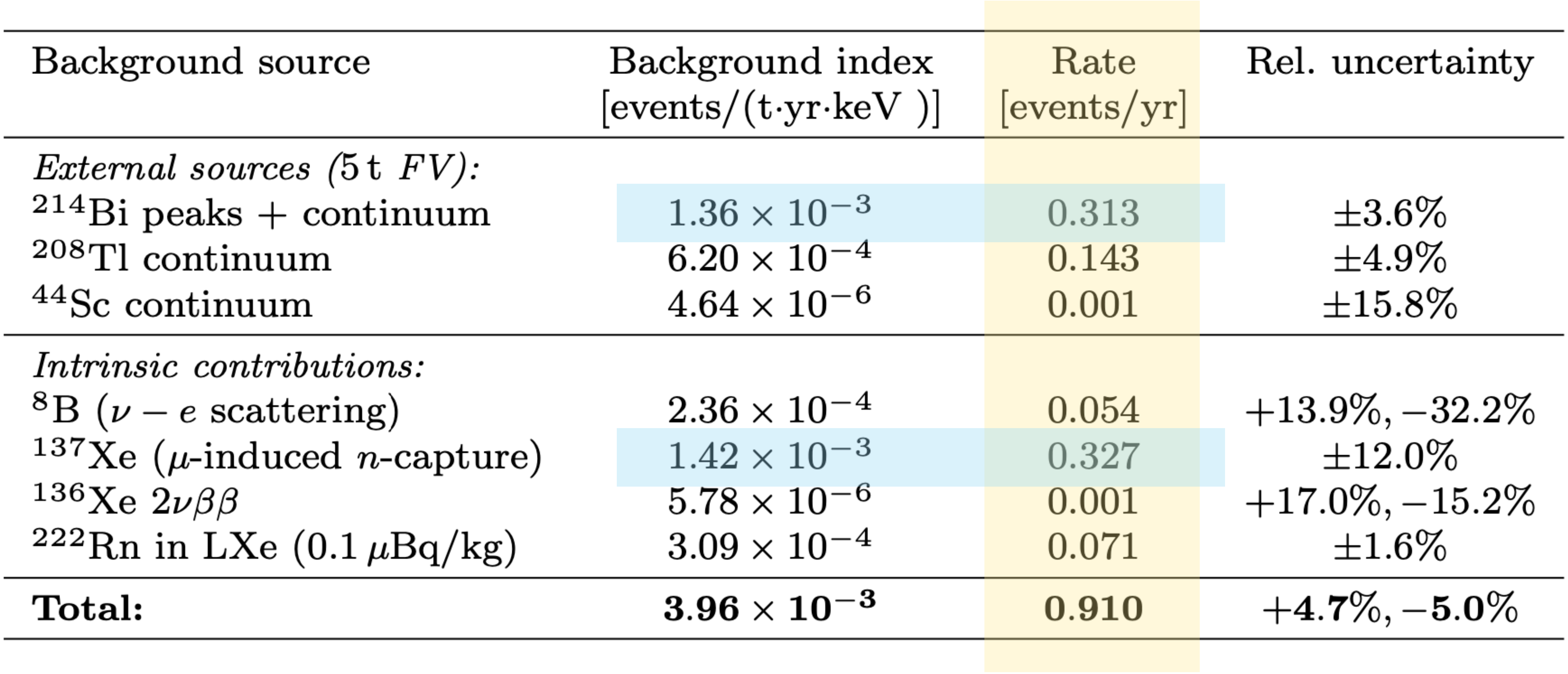
x-y position reconstruction ~ 1.5 mm resolution

SUMMARY

- DARWIN observatory: excellent sensitivity in particle/astroparticle physics
- Due to very low expected event rates, we need:
  - Large detector masses, ultra-low backgrounds (material radio-assay & Rn reduction remain crucial)
  - Very good energy resolutions, low energy thresholds
- In general: dark matter detectors are optimised at keV energy scales, double beta decay detectors at MeV-scale energies
  - Can we do both? Ideally, a large detector (DARWIN) with sensitivity to search for a variety of signals in particles physics (neutrinos, $0\nu\beta\beta$, axion/ALPs, dark photons, WIMPs, etc)
- Eventually limited by neutrino interactions (but also new physics opportunities!)
- Remember that yesterday’s background might be today’s signal ;-)

BACKUP SLIDES

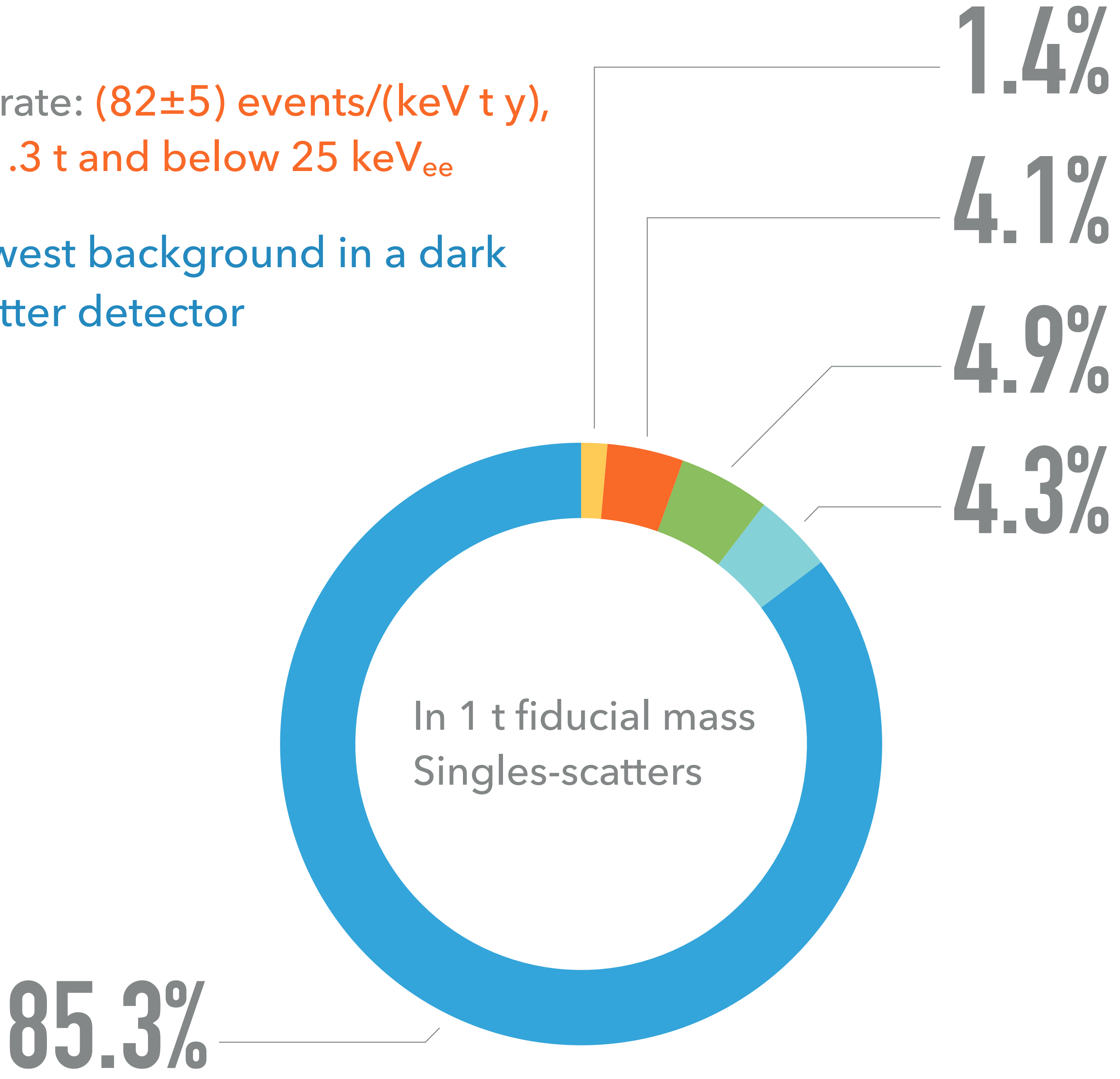
BACKGROUND BUDGET IN DOUBLE BETA REGION



Background source	Background index [events/(t·yr·keV)]	Rate [events/yr]	Rel. uncertainty
External sources (5 t FV):			
^{214}Bi peaks + continuum	1.36×10^{-3}	0.313	±3.6%
^{208}Tl continuum	6.20×10^{-4}	0.143	±4.9%
^{44}Sc continuum	4.64×10^{-6}	0.001	±15.8%
Intrinsic contributions:			
^{8}B ($\nu - e$ scattering)	2.36×10^{-4}	0.054	+13.9%, −32.2%
^{137}Xe (μ-induced n-capture)	1.42×10^{-3}	0.327	±12.0%
^{136}Xe $2\nu\beta\beta$	5.78×10^{-6}	0.001	+17.0%, −15.2%
^{222}Rn in LXe (0.1 μBq/kg)	3.09×10^{-4}	0.071	±1.6%
Total:	$\mathbf{3.96 \times 10^{-3}}$	**0.910**	**+4.7%, −5.0%**

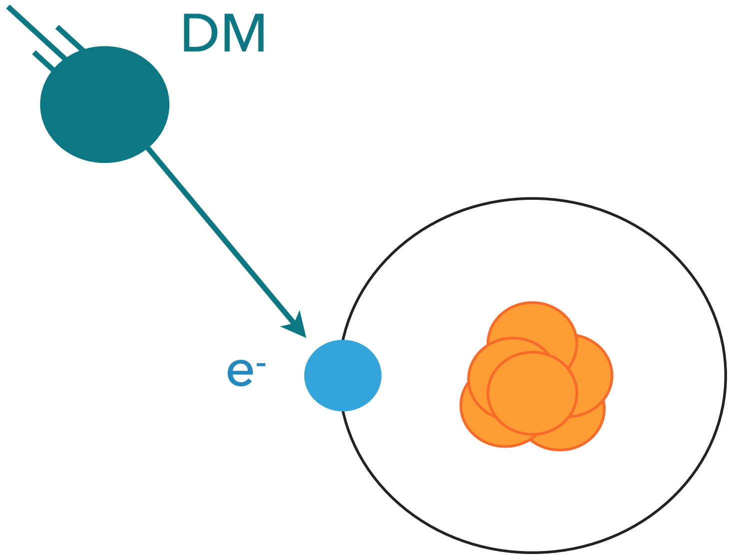
ELECTRONIC RECOIL BACKGROUNDS IN XENON1T

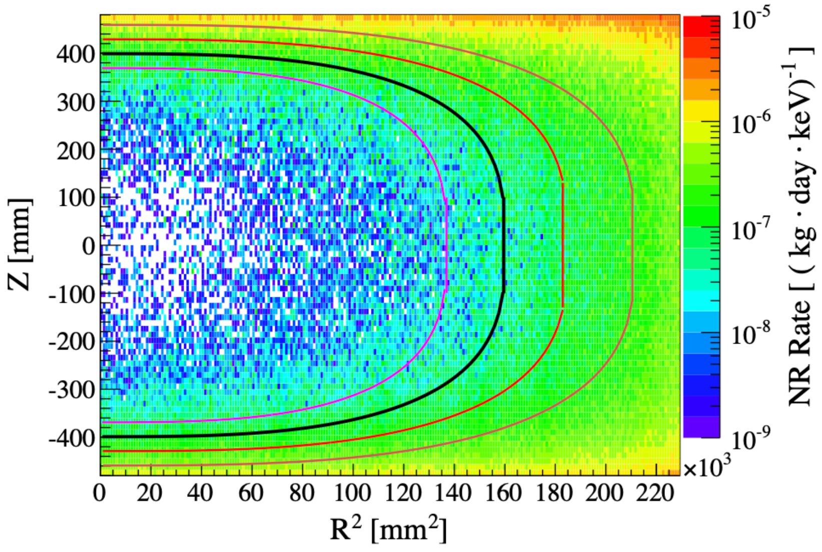
- ER rate: (82±5) events/(keV t y), in 1.3 t and below 25 keV_{ee}
- Lowest background in a dark matter detector



^{222}Rn (10 μBq/kg)

Control surface emanation
Reduce by online distillation



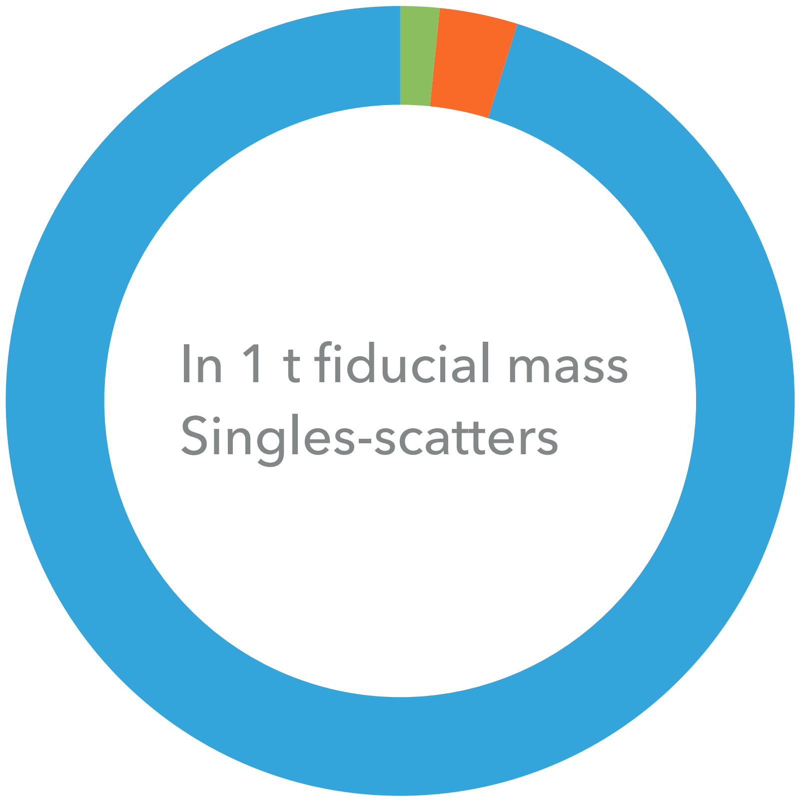


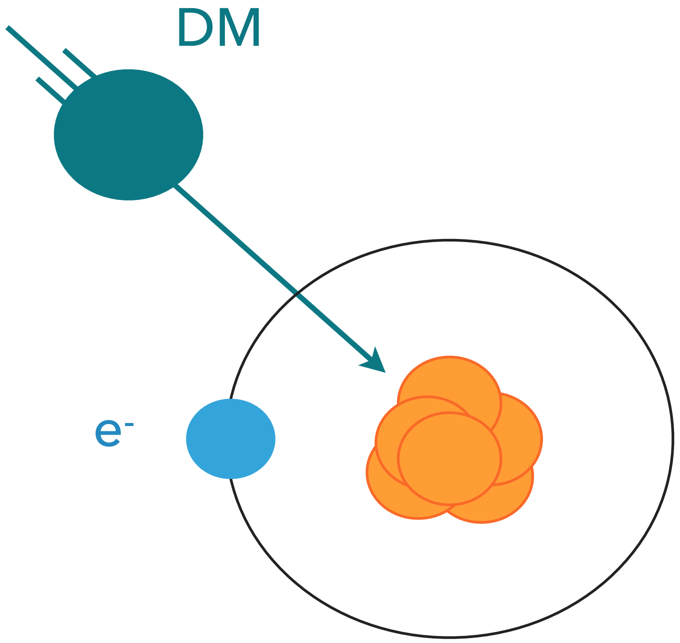
Cosmogenic neutrons (muon induced neutrons); rock overburden, water Cherenkov shield (here upper limit)

1.6%

3.2%

Coherent neutrino-nucleus scattering from ^{8}B neutrinos; irreducible, but relevant at low (<1 keV) energies





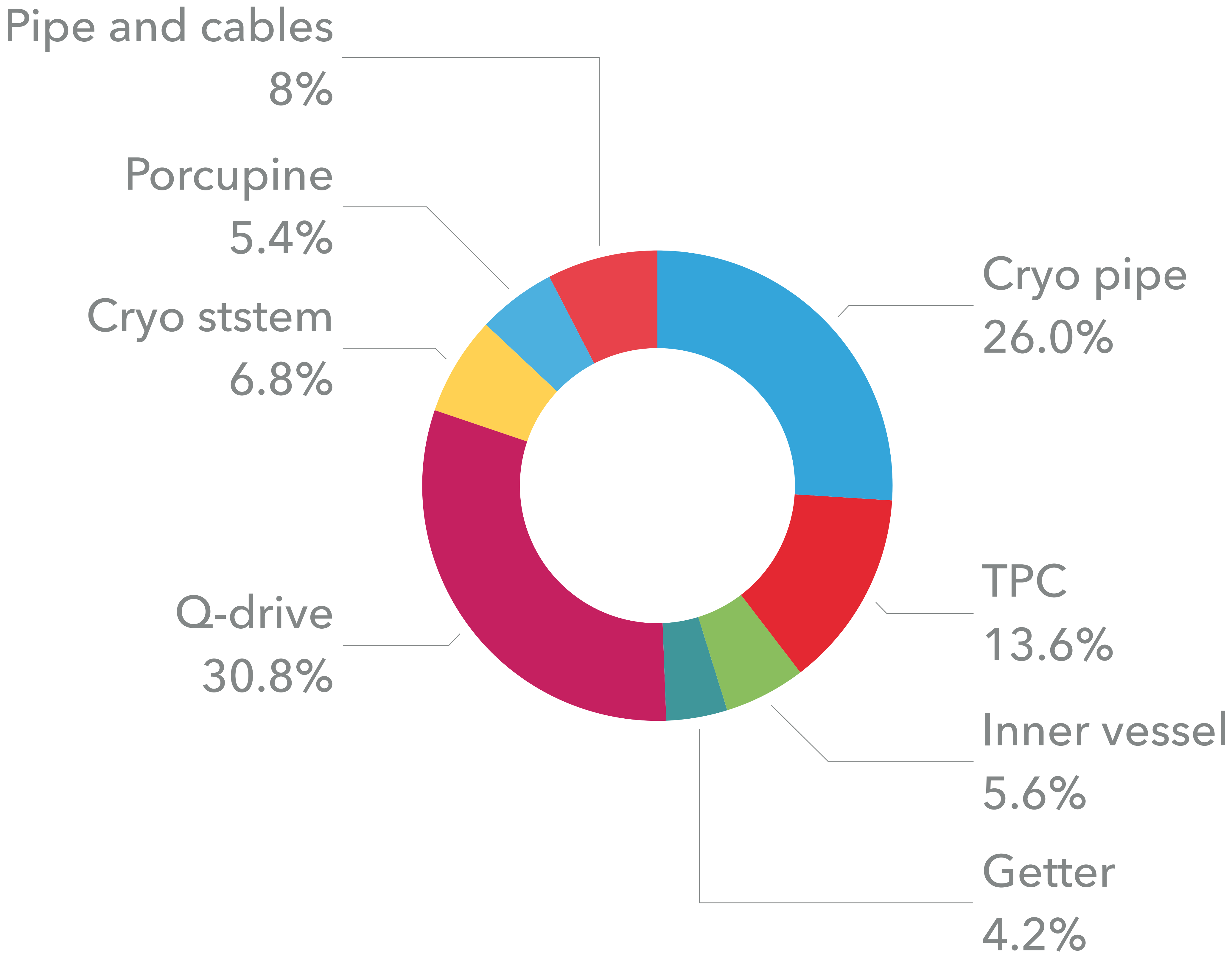
95.2%

Radiogenic neutrons

From (α,n) and SF reactions; material selection; single versus multiple-scatters

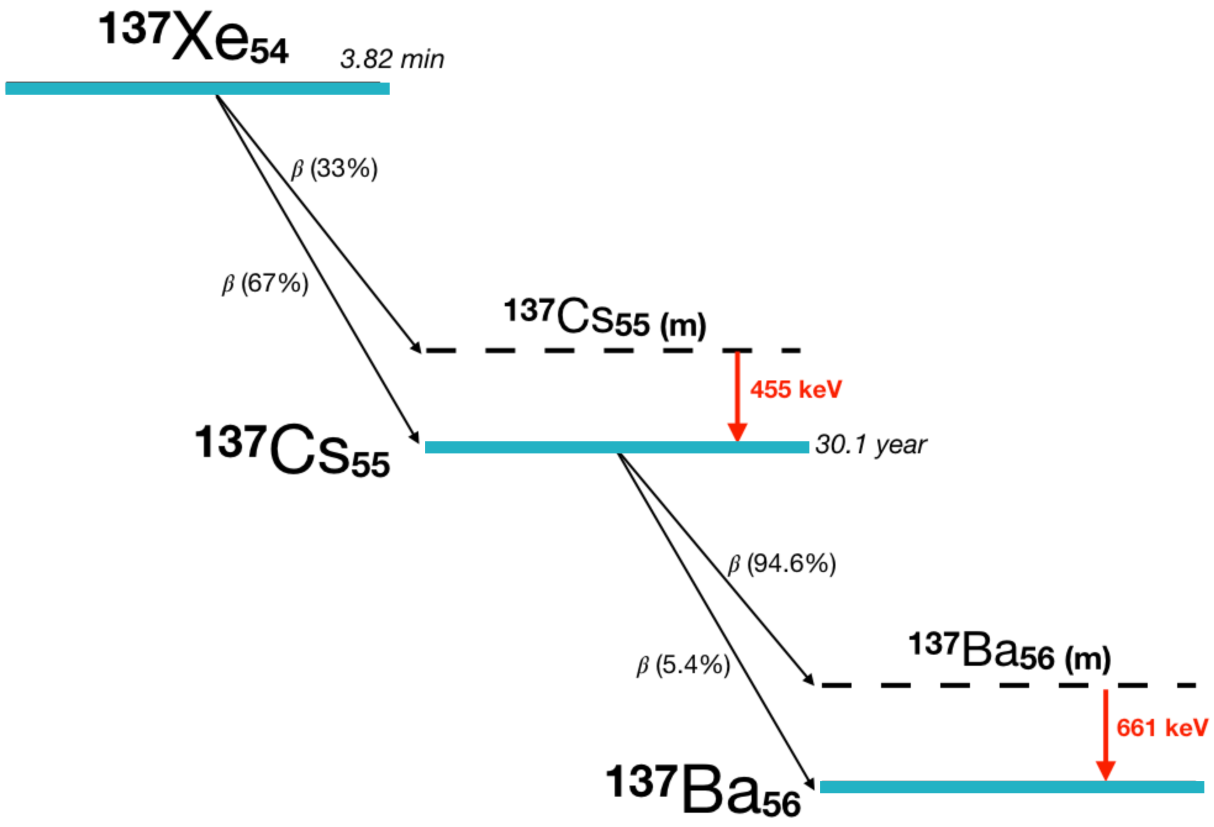
RADON BUDGET IN XENON1T

10 μBq/kg (before replacement of Q-drive pumps)

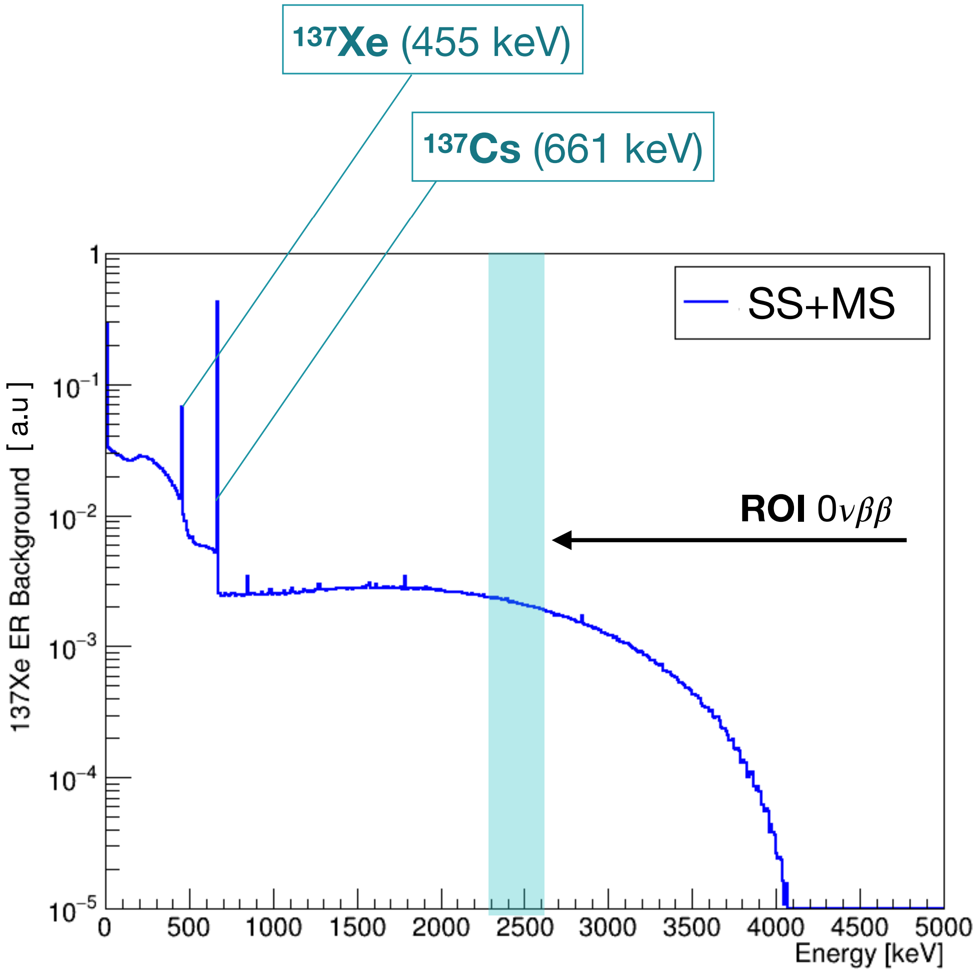


137-XE BACKGROUND

- Simulate ^{137}Xe, production rate by cosmogenic n-capture
- Rate: 6.7 atoms/(t y), dominated by production on LXe (6.3 atoms/(t y) (at LNGS, 3600 mw.e.)
- nEXO: 2.2 atoms/(t y) at SNOLAB (PRC 97, 2018); KamLAND-Zen: 1.42 atoms/(t y) at Kamioka (PRL 117, 2016)



Rate in ROI: (1.40±0.06) x 10^{-3} events/(t y keV)



ROI: Q-value ± FWHM/2 = (2435-2481) keV

137-XE BACKGROUND

- Simulate ^{137}Xe, production rate by cosmogenic n-capture
- Rate: 6.7 atoms/(t y), dominated by production on LXe (6.3 atoms/(t y) (at LNGS, 3600 mw.e.)
- nEXO: 2.2 atoms/(t y) at SNOLAB (PRC 97, 2018); KamLAND-Zen: 1.42 atoms/(t y) at Kamioka (PRL 117, 2016)

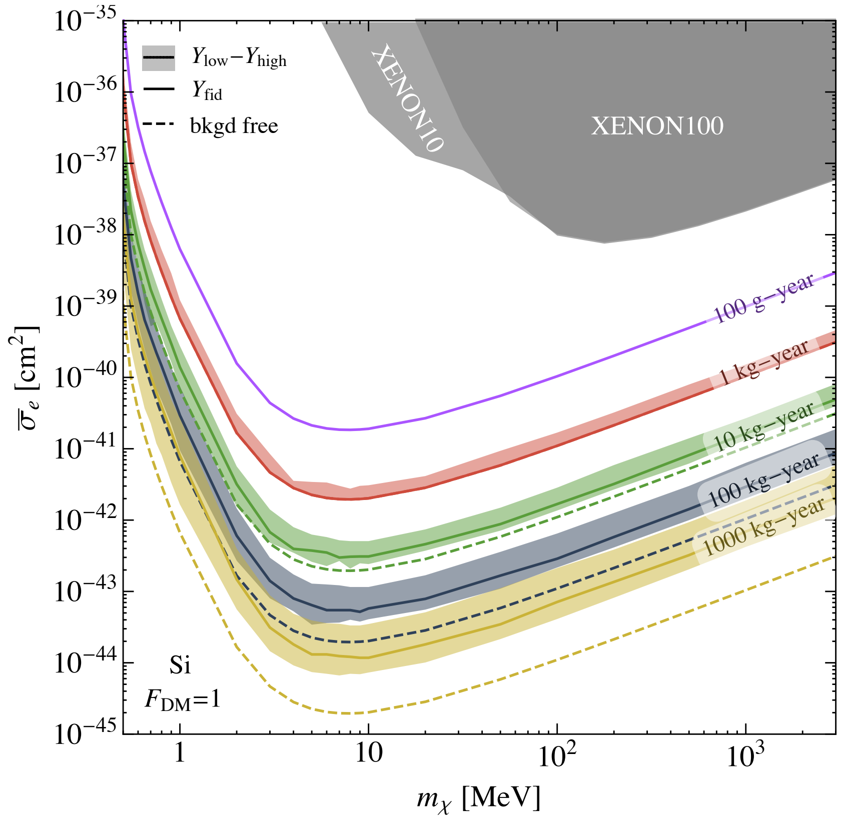
Material	**Muon-induced Neutron Production Rate [n/year]**	**^{137}Xe Production Rate [atoms/kg/year]**
Copper	1.12×10^{4}	7.39×10^{-5}
SS	1.32×10^{5}	2.40×10^{-4}
LXe	1.02×10^{6}	6.34×10^{-3}
Total		6.66×10^{-3}

Experiment	**Location**	**Depth [m.w.e]**	**^{137}Xe Production Rate [atoms/kg/year]**
KamLAND-Zen [2]	Kamioka	2050	1.42×10^{-3}
DARWIN	LNGS	3600	6.66×10^{-3}
nEXO [3]	SNOLAB	6011	2.20×10^{-3}

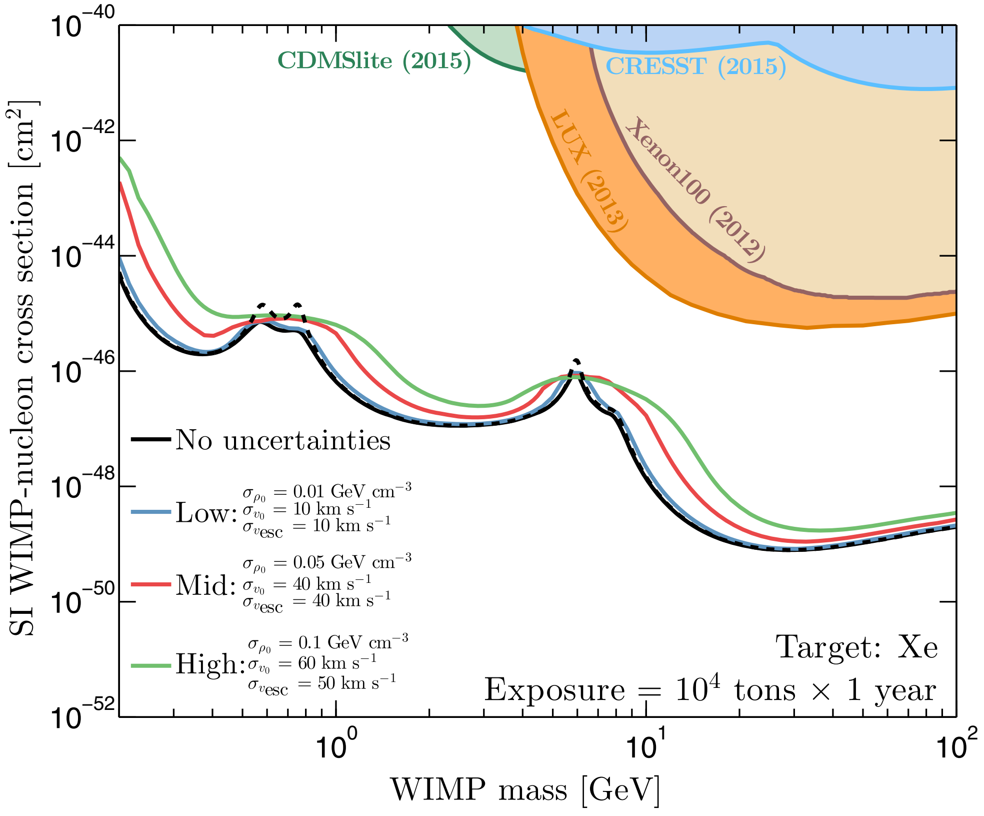
NEUTRINO BACKGROUNDS FOR DM SEARCHES

- Low mass region: limit at ~ 0.1- 10 kg year (target dependent)
- High mass region: limit at ~ 10 ktonne year
- But: annual modulation, directionality, momentum dependance, inelastic DM-nucleus scatters, etc

Discovery limits (2-σ) for various ionisation efficiencies Y, solar ν background only



DM-electron scatters (R. Essig et al, PRD97, 2018)



DM-nucleus scatters (C.A.J. O'Hare, PRD94, 2016)